NATURAL PHILOSOPHY.

(SEVENTH TREATISE)

ELECTRICITY.

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NOTICE.

ELECTRICITY is the branch of Natural Philosophy most closely allied to Chemistry. Hence, although in the order of study Chemistry comes after Natural Philosophy, a certain acquaintance with the primary facts of Chemistry will be of use in facilitating the comprehension of some portions of the present subject, particularly Voltaic Electricity. Before entering upon that department, the teacher will find it advantageous to state, and illustrate by a few familiar examples, the nature of chemical combination and decomposition, and to distinguish these from mixtures and separations that are not chemical. The leading properties of chemical union are the fixed proportions of the combining substances, the giving out of heat (as in burning), and the total difference between the resulting compound and either of the individuals in their whole aspect and properties. Thus a certain weight of sulphur, combining with a fixed proportion of copper filings, will produce heat while the union is going on, and will turn into a black substance in which neither copper nor sulphur could be recognised, and which could not serve any one of the special purposes of either.

In this, as in the preceding Treatises, great pains have been taken to render the arrangement as perspicuous, and the language as simple and intelligible, as the subject would allow.

ALEX. BAIN.

London, November 1848.

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ELECTRICITY.

OF POLAR FORCES IN GENERAL.

1. THE force of gravity is always of one kind, and is the same on all sides of a gravitating mass. The earth, as a heavy body, attracts all other heavy bodies, whatever be their shape or position. Constant and unremitted attraction is the peculiarity of this force. In like manner, the ordinary appearances of cohesion and capillary attraction are uniform under all arrangements of the particles or surfaces in contact. One drop of water is seen to attract another drop, a plate of glass attracts a liquid surface, both after an unvarying fashion. In the adhesion of the particles of a liquid among themselves, it is evident that each particle attracts the particle next it, whatever side it may present; for although we stir the mass about, so as to make the particles turn round among each other, they still show a mutual attraction. The whole surface round and round of an atom of water has an evenly-spread attractive power towards the whole surface of every other atom; whatever points are brought together, the degree of attraction will be equal, just as the earth will draw a body downwards with the same force on any side. In like manner the *repulsion* caused in bodies by heat, as in air (whose particles all tend to fly off from each other), is a constant repulsion. No movement among the atoms, as by stirring them and changing their places among each other, alters their repulsive tendency. It is manifest in this case also, that each atom of air is actuated evenly all round its body with a repelling power towards every other atom. If we supposed any one atom turned half round or quarter round in its place, it would

oppose different points to the atoms next it, but the new points would repel in exactly the same manner as the old.

2. But nature makes use of forces that have not the unvarying character either of gravity, liquid cohesion, or gaseous repulsion. We find a kind of force inhering in atoms and masses of matter that is repulsive at one side of each atom or mass, and attractive at the opposite side. If we have two bodies adhering to one another by this force, and if we take one of them and turn it about so as to place the opposite end next the other, there will be no attraction; on the contrary, there will be a repulsion, and this repulsion will probably have the same strength that the previous attraction had. In this case, therefore, the mutual position of the bodies is an essential circumstance. Each mass has its power gathered into its ends, but the ends have contrary actions. If the forces on two opposite points were joined together, they would neutralise each other, and cause perfect indifference on the whole. To forces of this character the name POLAR is given; and bodies actuated by them are called polar, or polarised, or are said to have the attribute of polarity.

3. When bodies are crystallised, the force by which their atoms adhere is a polar force. An atom of ice will not adhere to another atom on any side; a certain point of the one clings to a certain point of the other; and if one of a pair of adjoining atoms were to have its ends reversed, the two atoms would repel one another violently. Hence crystallised bodies cannot have their particles stirred about like a liquid, or like red-hot iron; the least disturbance causes a fracture. If a particle is moved from its proper position, it either ceases to attract or it becomes repulsive, and there is an end to the cohesion. The property of *brittleness* generally indicates a polar cohesion. Malleability and ductility, or mobility of parts, show that the cohesion is not polar, but general, and evenly distributed over the entire surface of the particles. When bodies are at their highest pitch of solidity, hardness, or compactness of structure, they have generally the polar cohesion. This cohesion is uniformly destroyed by heat, which softens, melts, and finally evaporates solid substances. And in many other cases besides crystalline cohesion, heat is the destroyer of polarity.

4. Throughout the whole range of actions that are included under ELECTRICITY, polarity is an invariable characteristic. It is not possible to produce an electrical attraction without an equal repulsive power conjoined. Every electrified body is attractive at one end and repulsive at the other, or is polarised, like an atom of a crystal. It is in electricity that we can most completely study the nature and laws of polar force,

for there we have it under the greatest variety of different circumstances and modes. It is not confined to electricity; we see it also in light. Chemical forces have certainly a polar nature, and some of the vital forces appear to have the same character. Whether all the polar forces arise from one identical agency or from many, they at least serve to illustrate and explain each other; and the electrical phenomena present the most visible and tangible instances of the polar mode of action.

5. The word "electricity," taken from the Greek name for *amber* (which strongly exhibits the phenomena when rubbed), was at first applied to the electrifying of bodies by rubbing or friction; but it is now the general name for seven different kinds of electrical excitement. These seven kinds fall under two heads. When the excitement is in a state of repose, and maintains itself, it is called STATICAL ELECTRICITY; when the excitement is in a constant current, and requires to be continually renewed, it is called CURRENT ELECTRICITY. The subdivisions of each are as follow:—

STATICAL ELECTRICITY.

1. Magnetism.
2. Frictional or Tension Electricity.

CURRENT ELECTRICITY.

3. Voltaic Electricity.
4. Electro-Magnetism.
5. Magneto-Electricity.
6. Thermo-Electricity.
7. Animal Electricity.

MAGNETISM.

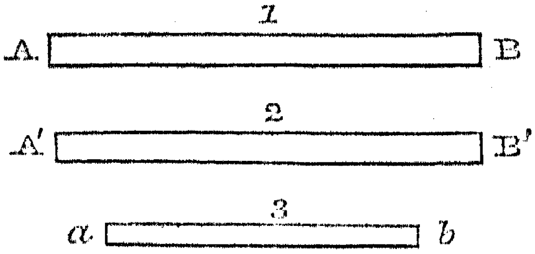
6. There is a certain ore of iron (an oxide, or a combination of the metal with oxygen) that has the property of attracting pieces of iron, and of communicating its attractive power to bars of steel. This ore is called the *loadstone*. The name *magnet*, also applied to it and to the bars of steel that have acquired its properties, is supposed to be derived from Magnesia, a country in Asia Minor, where it was first discovered.

LAWS OF MAGNETIC PHENOMENA.

7. The first principle of the magnetic force may be stated thus: *The magnet has always two poles or points where the power seems concentrated.* If we dip a magnetic bar into iron filings, on lifting it up we find a considerable quantity of the filings adhering to it, in consequence of its attraction for iron. On observing it closely, we see that the greatest mass of filings is attached to the two ends, that there is a gradual decrease towards the middle, and that in the middle point itself there is none. Hence it is said that the poles, or centres of the force, lie in the ends of the bar. A heavier piece of iron will be suspended at one of the ends than in any other place. The actual poles or points of highest concentration in the case of a bar, are each in the interior of the bar at a small distance, probably from a quarter of an inch to an inch from the extremities. Whatever be the shape of the magnetic mass, two such centres will be found in it. If a loadstone, or a steel magnet, is broken in two, each fragment will have two poles the same as the entire body; and this would hold if it were broken into any number of pieces. The poles are not of themselves the sources of the power. They resemble rather the centre of gravity of a body; which is the point, not where the gravity is actually lodged, but where, if it were lodged, the action of the body would continue the same; and which is continually changing with the changes of shape or contents that the body undergoes. The magnetic poles represent the total magnetism of the mass; when we speak of a body's distance from the magnet, we measure this distance from a pole. As a gravitating mass is a collection of gravitating atoms, so a magnet is a collection of magnetic atoms, each with its two poles; and when the forces of all the atoms are joined together, the result is the same as if the magnet were only a pair of atoms, placed

asunder at the distance of the two poles, and possessing opposite attractions.

8. *Magnets repel each other by their like poles, and attract each other by their unlike poles.* The two poles of a magnet, as of all polarised bodies, have opposite actions; what the one will attract, the other will repel, and what the one will repel, the other will attract. If we have two different magnets, and if we take a third magnet to try their action upon, we shall find out which is the like, and which the unlike poles. Present one end of the first to one end of the third; and suppose we find that they attract each other. Present next one end of the second to the same end of the third; if an attraction now takes place, the poles of the first and second that have thus shown a common attraction for one pole of the third, are *like* poles; they have both precisely the same action on one object. Their other ends, if tried in the same way, would show an identical action on the common object, and would also be like poles. But if a pole of the first attracted, and a pole of the second repelled, the same pole of the third, the poles of the first and second thus tried would be unlike poles. Thus, in the figure, suppose that the pole A of No. 1 attracted the end *b* of No. 3, and the pole A′ of No. 2 also attracted *b*, A and A′ are like poles; but if, while A attracted *b*, A′ repelled it, A and A′ would be unlike poles. Now, from the nature of polarity, the two poles of the same magnet are always unlike; that is, if A attracted *b*, B would repel *b*. By reversing the acting magnet while the magnet acted on remains, we get an opposite action.



9. Supposing, therefore, it is found by such a trial that A and A′ are the like poles of two magnets. Let us bring these two poles together, and the action is repulsion. So, if we bring the other ends together, B and B′, which also are like poles, they will repel each other. But if we bring A and B′ together, which are the unlike poles of the two magnets, they will attract each other, and adhere with more or less force according to their strength. The same will happen if we bring A′ and B together. And if, in the trial of the two first upon the third, it appeared that A and A′ attracted *b*, this would be a proof that the pole *b* was unlike the poles A and A′, and like their opposites B and B′; and that *a* is the pole like to A and A′.

10. The two poles of a magnet are distinguished by the

names North and South, from the north and south poles of the earth. The end of a magnetised needle or bar that points to the north pole of the earth when suspended freely, was at an early period termed the north pole, and the opposite end the south pole. This usage still continues, although erroneous. In fact, the end that is attracted to the north is, for that very reason, *unlike* the north magnetic pole of the earth, and ought to have been termed the south pole of the magnet.

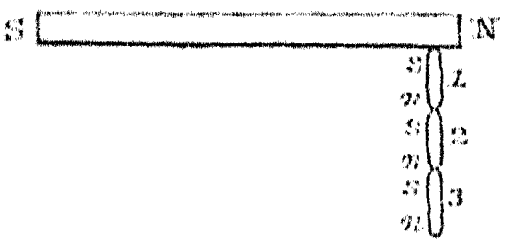
11. It thus appears that there exists within each magnet two contrary influences, which repel each other, and, through this repulsion, are distributed into the two farthest ends of the mass. Half-way between the poles is the cross line of neutrality. It is the place where the two opposing forces balance one another, and prevent an attraction taking place either way. We must regard the force even at one of the poles as a difference of two forces; for when a needle is attracted to the north pole of the magnet, it is under the repulsion of the south pole at the same instant. It is kept to the north pole only because it is nearest; for the magnetic force diminishes by distance. It is from the neutral line being equally distant from both poles that its neutrality arises. An object placed there is like the matter in the earth's centre, which, being equally attracted on all sides, shows no tendency to any.

12. *The attraction of magnets for unmagnetised iron arises from a temporary communication of magnetism, called induction.* If we bring a few iron filings or pieces of soft iron near the pole of the magnet, they will be attracted; if we take them off, and apply them to the other end, they will still be attracted. This at first sight appears to contradict the general statement as to the contrary nature of the two poles. But on nearer examination, it becomes perfectly consistent; and a new property of magnetism is disclosed by it. When we bring one end of a piece of soft iron near the pole of the magnet, the soft iron is itself rendered magnetic. Each magnet is, as it were, surrounded with an atmosphere that communicates the power to all iron masses that approach it. This temporary magnetism is always arranged in opposition to the forces of the principal magnet. The end of the soft bar touching the north pole of the magnet becomes a south pole; and the other end is a north pole, as may be seen by bringing the south pole of another magnet near it. While in actual contact with the magnet, the iron is not indifferent; if we try the remote end by a pole like the one that attracts the near end, we will see an active repulsion: so that a magnet attracts iron because it has the power of making it a magnet

for the time. The iron in contact is rendered polar throughout, and has this polarity concentrated in two opposite poles exactly like the loadstone. A magnet cannot attract silver, because it has not the power of imparting the magnetic state to atoms or masses of silver. Iron seems by nature susceptible of magnetism, and when once it is magnetised, it can attract other iron by magnetising it in turn.

13. The existence of this temporary influence, called *magnetic induction*, proves that polar bodies attract none but polar bodies. When a neutral body is brought near a polar body, there will be no action unless the neutral body is first polarised by the neighbourhood of the other.

14. When a magnet suspends iron filings, they may be seen hanging from it in threads, clinging not all to the magnet, but to one another in a chain. This action is best understood by taking a few iron balls or little bits of wire, and suspending one of them to a pole of the magnet. By this suspension it is made a magnet for the time, and two active poles are developed in it. If the north pole of the magnet is used, the wire 1 will have its upper end a south pole, and its lower end a north pole, ready to attract iron, as if it were a permanent loadstone. Bring now the wire 2 into contact with the first. The active north pole of No. 1 will develop an active south pole in the upper end of No. 2, and an active north pole at its lower end; the unlike poles will attract each other, and the second will hang by the first, and will have the power of communicating the same polarity, and exercising the same attraction for a third wire. The weight of wires that can be polarised and suspended is limited by the power of the magnet. As the lower end of the above series is a north pole, it may be carried across to the other end of the magnet which is south, and there attracted; and we will thus have a chain hanging from end to end of the magnet, each joining presenting a pair of opposite poles. The inductive strength of the two ends being combined in this case, a greater weight will be sustained than could be borne by a single pole.



15. We must conceive the atoms composing the magnet itself as exercising the same inductive power on one another, and in this way combining their strength together. But for this power which each little magnet has to throw its strength, as it were, into an adjoining magnet, there could be no accumulation of force. A chain never can be stronger than its

weakest link; and the end of a line of magnetic atoms would have no greater strength than a single atom unless each atom was heightened by the inductive force of the whole series. No. 1 has of itself a certain degree of polarity; No. 2 has in like manner a certain independent strength; when the two go together, the first adds its inductive strength to the natural polarity of the second, and the second does the same to the first, and each is now so much stronger than before. It is like the lowest stratum of a fluid which presses not only with its own gravity, but also with the accumulated gravity of all that lie above it.

16. *The power of the original magnet is exalted by the induction.* By connecting the two ends of a magnet by a rod of unmagnetised iron, the latter becomes magnetic under the induction, and seems to react upon the magnet by its induction, so as to maintain, and even to increase, its polarity. Left to itself, with its poles unconnected, a magnet's power gradually decays. The series of inductive polarities must form a circle to acquire the highest degree of intensity; and when an unmagnetic bar joins the poles, the exercise of the induction upon the fresh matter gradually heightens the sum of the polarity.

MAGNETS.

17. *The loadstone* has been termed the natural magnet, because it seems to have magnetism permanently engrained in its constitution. It is found in all parts of the world, and sometimes forms rocks of considerable size. Its strength is very unequal in different specimens. As a general rule, a small loadstone will carry a greater weight in proportion to its size than a large one. It has a grayish colour and a dark metallic lustre. Although an oxide of iron, it is not identical either with rust or with the scales of iron formed by burning iron wire in oxygen gas.

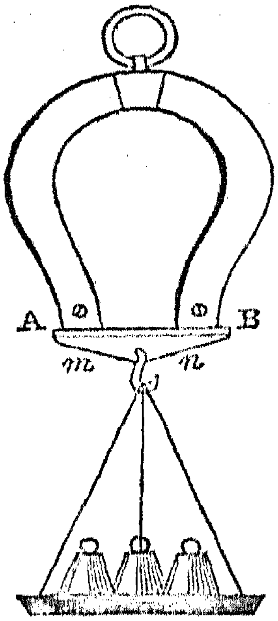
18. Artificial magnets are formed from bars of well-tempered steel. The instantaneous influence of a magnet on a steel bar is not so great as on soft iron, but the steel retains the polarity that has once been communicated to it. To magnetise the steel thoroughly, motion and friction are used. In general, if we take a loadstone, or a bar already magnetised, and rub one end along a steel bar repeatedly, and always in one direction, the steel bar will become magnetic; but in order to make the process effective, a mode of action must be used that uniformly tends to give one kind of magnetism to the bar—that is, that always developes the same pole at the

same end. If one part of the stroke tends to give a south pole, and another a north, to one end of the bar, the contradiction will destroy the effect. In rubbing a bar with a magnet, we ought to commence at the middle of the bar, and rub from thence to one end with one of the poles of the magnet; the magnet should then be reversed, and placed at the middle as before, and rubbed towards the other end of the bar. And the process should be repeated in the same order; one end of the magnet always going out to one end of the bar, and the other end of the magnet to the other end of the bar alternately. The bar will then be magnetised in such a manner that each end will be opposite to the end of the magnet that rubbed it. The same inductive action that renders soft iron temporarily magnetic by mere contact, comes into play here; but steel offers more resistance to the action than iron, and the friction is needed to overcome the resistance. The magnetic state thus forcibly communicated remains permanently in the steel bar, which has thenceforth the character of the natural loadstone.

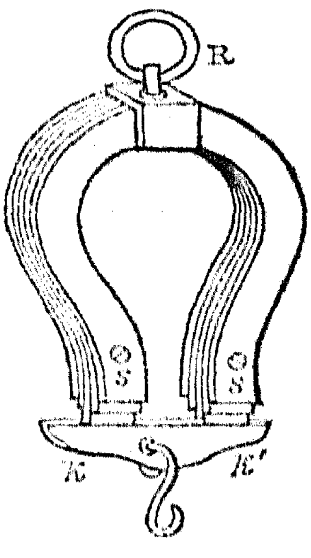
19. In practice, it is found best to use two magnets to rub with, and thereby to perform both the rubbings at once. Opposite ends of the two rubbing magnets are laid together on the middle of the bar to be magnetised, and they are held so as to make a small angle with the bar; they are then drawn along, one to one end, and the other to the other end, repeatedly. The bar itself is laid in a straight line with two other magnets, which exert upon it the inductive contact while it undergoes the friction of the rubbing magnets. This method is found very suitable in magnetising needles for compasses. Another method, called the *double touch*, consists in arranging the bar as before, with magnets in a line with each end, and using two rubbing magnets with opposite poles brought together; but instead of beginning at the middle of the bar, and separating the two, and drawing them apart to the two ends, they are held together and rubbed from end to end backwards and forwards. The inclination in this case is to be still smaller than before. The ends of the rubbing magnets are not in actual contact, but press upon a wedge of wood or brass which lies between them. This method communicates a very intense degree of magnetism; but is apt to make the poles of the bar unequal in strength.

20. Instead of being a straight bar, it is convenient to give magnets the form of a horse-shoe, which brings their poles near each other, and makes it easy to complete the circle, and to bring both poles into play upon the same object. Such a magnet is represented in the following figure. A and B are

the two poles; they are joined by the bar *mn*, which is of course polarised; *m* having the opposite magnetism from A, and *n* from B. Each horse-shoe magnet is permanently furnished with such a cross-piece, made of soft iron, which is called the *keeper*, and sometimes the *lifter*, and also the *armature*. When the magnet is used to suspend weights, these are attached to the keeper, as shown in the figure.



21. In order to make a very powerful magnet, a number of single bars are joined together. This makes a *compound magnet*, or a magnetic bundle or battery. They may be either straight or horse-shoe bars. A compound horse-shoe magnet is represented beneath: R is the ring for suspending it, and *kk'* the armature; the bars are magnetised before being joined, and they are fastened by screws *s* and *s* running through them.



22. A piece of loadstone is generally fitted up in a framework of soft iron, and its poles are thus communicated to projecting ends of iron, which have the same action as the ends of magnetic bars.

23. The strength of a magnet may be gradually heightened by hanging weights to it, which are to be increased at intervals of time by little and little. On the other hand, the magnet is weakened by abruptly breaking the contact, as in drawing off the keeper suddenly. If an iron bar is in inductive contact with a magnet, and in that position receives a succession of blows with a hammer, it will acquire a fixed magnetism: so, if it is placed under induction while hot, and allowed to cool, the magnetic state will be confirmed so as to remain; also if iron, while under induction, becomes rusty, the chemical action will have the same effect in fixing the magnetism. On the principle that a change in the molecular constitution of the iron can render permanent the magnetic state, it is possible to form an artificial loadstone. On dipping a powerful horse-shoe magnet into iron filings, a great mass will be aggregated round each pole, and they will run together so as to make a string or tuft between the poles. The whole mass taken together will be as one magnet of loose cohesion. If the filings are then moistened with oil, and exposed to a

red heat while connected with the magnet, a partial oxidation of the iron will take place. The mass will then cohere together with some degree of compactness, and will remain permanently magnetic, and very much resemble the natural loadstone. On the other hand, a magnet when heated to redness and then cooled, loses its magnetism entirely, as well as its steel temper. Red-hot iron loses the power of being attracted by the magnet, and seems to become like one of the indifferent metals. On closer examination, however, and by the use of a magnet of very great power, Faraday found that the magnetic susceptibility is not entirely lost at a red heat, but merely very much enfeebled.

24. Iron is not the only magnetic metal, although it be the one most powerfully affected. Nickel and cobalt are also magnetic, and are attracted and polarised exactly like iron. It was formerly supposed that all the metals might be subject to magnetism in some degree, although perhaps it might require a much lower temperature than ordinary to make the polarity appear; but the recent experiments of Faraday are tending to show that only a limited number of them are magnetic; namely, the three already decided on—iron, nickel, and cobalt; and as far as appears at present, six others—titanium, manganese, cerium, chromium, palladium, and platinum. To these nine bodies must now be added OXYGEN, which Faraday has still more recently shown to be magnetic.

25. A certain number of metals when under high magnetic influence—as when lying between the poles of a powerful horse-shoe magnet—are repelled by both poles alike, so that a bar suspended between two poles is compelled to assume a cross position, from its seeking to be removed as far as it can be from both. To this action Faraday has given the name of *diamagnetism*, or cross magnetism. It is, however, radically different from magnetic action, although caused by a magnet. Its want of the polar character makes it an exception to all forms of electrical excitement. It takes place so decidedly on the following metals, as to prove them to be at least not magnetic—antimony, bismuth, cadmium, copper, gold, lead, mercury, silver, tin, zinc. But the cross action is not confined to metals: it belongs to almost all solid, liquid, and gaseous substances, excepting those that are magnetic; and it may belong to them too for anything we know, since, though it did exist, it would be overpowered and hidden by their magnetic tendency. The diamagnetic action is found to be strongest with bismuth, phosphorus, and the heavy glass, composed of silicated borate of lead.

26. When a substance is magnetic, like iron, all its com-

pounds are magnetic likewise. Oxides and salts, and the other combinations of iron, nickel, cobalt, titanium, &c. are all attracted by the magnet, and consequently excluded from the list of Faraday's diamagnetics. Liquid solutions of the acids and salts of these metals are seen to be magnetic as well as the solid masses. Hence if any compound of a metal shows polarity, or is attracted by a magnet, that metal is inferred to be magnetic. It was principally by the use of compounds that Faraday determined the magnetic character of the six metals above enumerated additional to iron, nickel, and cobalt. The magnetism of oxygen, however, is not maintained in its compounds.

MAGNETISM OF THE EARTH.

27. The earth, taken as a whole, forms a great magnet having two poles, termed its *north and south magnetic poles*. This is proved by the fact, that all magnets assume a fixed position on its surface, in a direction nearly north and south. If we suspend a magnetised bar with a string, and leave it to itself, on coming to rest it will take this north and south direction; and if we move it or whirl it round, it will come to rest again in the same position. The exact direction of the magnetic needle, or freely-suspended bar, in any place on the earth, determines the *magnetic meridian* of that place; which is an imaginary upright plane (like those used in astronomy), passing through or along the bar thus suspended. This meridian is not always due north and south, and consequently it does not coincide with the astronomical meridian. Its deviation from the latter is called the *declination*. This declination is sometimes east and sometimes west. It is also called the variation of the compass; and in using a compass to determine the true north point, allowance must be made for such variation.

28. The declination varies in different places, and is constantly changing for any one place. Its change is steady and progressive: after increasing up to a certain point on one side, it decreases, comes to nothing, and passes to the other side, where it increases to a maximum, and then commences to retreat. Thus in 1660 there was no variation in London; the needle lay exactly north and south. In 1700 it had acquired nearly 10 degrees of deviation to the west, which went on increasing in this direction during the whole of last century; and in 1800 it amounted to upwards of 24 degrees. From 1815 downwards it has been slowly decreasing. It must take several hundreds of years to go through an entire course. Besides this general movement in one direction, the needle shows other variations: it has a small daily vibration called the *diurnal variation*. From sunrise it begins its

westerly sweep, which continues till about five P. M.: it then retrogrades, and continues to move east until it has reached its mean position, where it settles through the night. This arises from the sun's action on the oxygen of the air (23, 24.)

29. If a bar or needle is made to balance itself level or evenly in an axis before being magnetised, it will not lie even, if placed in the magnetic meridian, after it has been rendered a magnet. It points downward, or is said to *dip*. This dip or *inclination* of the needle is so great in some places as to make it stand nearly upright. But the dip varies with the latitude. On the equator the needle is nearly level; in the regions about the north and south poles it approaches the upright position. In this country it inclines or dips about 70 degrees. It is evidently owing to the earth's magnetic poles being situated deep in the interior of the globe somewhere in the arctic and antarctic circles. Captain Ross came to a place in 70° 5′ north latitude and 263° 14′ east longitude, where the needle stood perfectly upright, showing that the north magnetic pole was directly under that spot, being thus at a considerable distance from the north pole of the earth. On the other hand, there are places in the tropics where the needle has no inclination; and every such place is said to be in the *magnetic equator*, which is formed by drawing a line through all the points where this perfect level occurs. The magnetic equator does not coincide with the earth's equator, but deviates to each side of it, and forms on the whole a very irregular line. The level of the needle is evidently produced by the equal and opposing actions of the north and south poles. North of the magnetic equator the dip is north, and south of the equator it is south.

30. There is the same constant fluctuation in the inclination as in the declination of the needle. The inclination has been gradually diminishing in London for the last century. It also has daily variations. The aurora borealis has always an effect upon the magnetic needle, both in its declination and its inclination. Earthquakes and volcanic eruptions are accompanied with magnetic disturbances, which sometimes cause a permanent alteration of the needle. There occur, besides, agitations, called magnetic storms, which sometimes affect a whole continent simultaneously, and produce large vibrations in all the magnetic instruments. From all these circumstances, it appears that the earth's magnetism is undergoing incessant fluctuations and changes, some gradual and steady, others sudden and momentary.

31. Besides the inclination and declination caused by the earth's magnetic polarity, the *intensity* of the action has

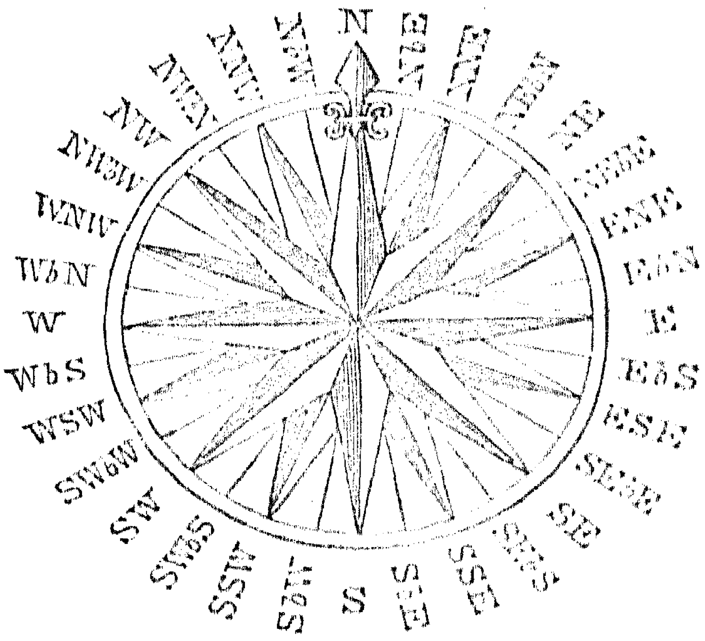
been made a matter of observation. This is measured by a separate instrument, and it is found to be least on the magnetic equator, and to increase gradually towards the magnetic poles; but like the other two elements, it is continually varying in the same place.

32. In regard to inducing magnetism upon iron, the earth acts like an ordinary magnet.. A bar of iron, pointed to the pole like a dipping needle, and hammered, or cooled, or rusted in that position, becomes a magnet. So certain is this effect, that hardly any iron is ever found free from magnetism. The earth's inductive effect is rendered permanent in pieces of iron by the various modes of working and employing them, as well as by the spontaneous oxidation which occurs when they are lying unused. In high north latitudes, pokers and bars that usually stand on end inevitably acquire a small degree of magnetism. In the tropics, bars which lie on the ground nearly north and south are affected in a similar way.

33. The magnetic force, like all other influences spreading or radiating from a centre, diminishes as the square of the distance increases.

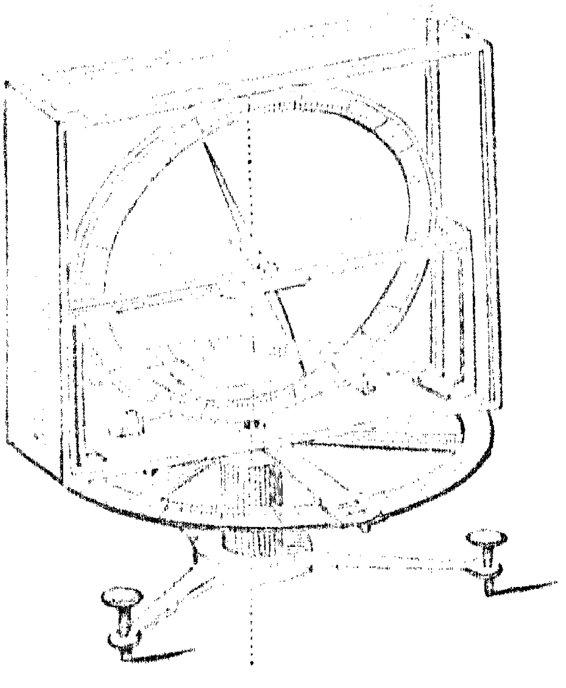
MAGNETIC INSTRUMENTS.

34. The apparatus designed to exhibit magnetic actions, not only serve for the study of the phenomena in a scientific point of view, but have also very important practical applications. The *mariner's compass*, which is a declination needle, serves to guide navigation in the open ocean, when there is no mark either in the sky or on the visible horizon to distinguish north, south, east, and west. By pointing always to the north, or within a known angle of the ex[redacted]north point, it shows the course of the ship at every moment. The most essential part is a magnetised bar of steel, called the *needle*, which is supported horizontally on a central pivot, round which it is free to move and to point in any direction. The pivot rises from a circular *card* or dial, round the circumference



of which are marked thirty-two *points*. The preceding figure represents this card :—North, south, east, and west, are the main or cardinal points, and are indicated by their initial letters respectively, while the subordinate points are also marked by letters, as N *b* E for north-by-east, N N E north-north-east; and so on. To be able to recite the various points is said to "box the compass." The card and needle are fixed in a round *box*, enclosed by a sheet of glass, to secure it both from the agitation of the atmosphere, as well as to exclude dust, moisture, and other things which might interfere with the correctness of its indications. The whole is enclosed in another box, suspended by two concentric brass circles, or *gimbals*, as they are technically called, and in such a manner, that the compass hangs, as it were, on points like a swivel, by which, during the pitching and rocking of the ship, the needle and its card remain in a horizontal position, and under all circumstances of motion indicate the various points correctly.

35. The *dipping* or *inclination needle* has to be suspended on an axis, with an upright graduated rim attached to it, to show the amount of the inclination. The instrument is represented complete in the figure.



36. A great improvement has been effected in the use of the compass by taking into account the action of the iron of a ship upon it, and providing a method of neutralising this action, whose effect would of itself render inaccurate the indication of the needle. A ship necessarily contains a large quantity of iron, which is sure to have some degree of magnetic power; and as the compass hangs in the stern, the attraction of the iron will always tend to make the needle turn to the direction of the ship's motion. It has been actually found that this source of disturbance is sufficient to cause very great mistakes as to the courses of vessels. The remedy for it was invented by Barlow, and is called *Barlow's Protecting Plate*. It is a plate of iron, fixed behind the compass, or between it and the stern of the ship, which of itself would produce a disturbance of the needle; but it may be so adjusted that its action shall be exactly equal to the action

of the other iron of the ship. Although this counteracting plate weighs only a few pounds, yet, by its nearness to the needle, it can be made as powerful as the whole mass of the ship's metal, whose average distance from the compass is necessarily considerable. The adjustment is made by finding out first the disturbance produced by the vessel on the compass; which is done by comparison with a compass placed out of the reach of the disturbing influence. The plate is then mounted in connection with the compass, and moved farther or nearer till it cause exactly the same amount of error, and the position thus found is made permanent. The ship's compass is taken on shore when this last operation is performed; and a complete neutrality can thus be effected.

THE MAGNETIC FLUIDS.

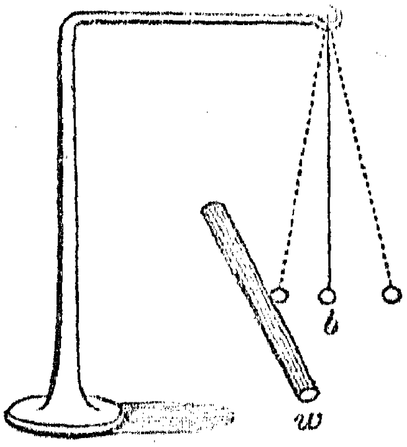
37. To account for the magnetic phenomena, it has been supposed that there are contained in the structure of iron and other magnetic substances two subtile fluids destitute of weight, colour, or sensible appearance, but imparting great energy to the solid matter. A portion of one fluid strongly repels another portion of the same fluid, but strongly attracts a portion of the other fluid. Each atom contains about it a certain quantity of both. In the unmagnetised state, the two neutralise each other, and have no influence of any kind; but by excitement, one fluid is driven towards one end of an atom, and the other accumulated at the other end. Being prevented, by the cause which rouses the excitement, from coming together upon the same atom, through their mutual attraction, they produce attractions between adjoining particles. The fluid accumulated at one end of one atom attracts the opposite fluid at the end of another atom; and as the fluids cannot quit their respective atoms, these are drawn together at their unlike ends. When two atoms are lying contiguous, if one has its fluids excited and polarised, the fluid accumulated at one end will draw the opposite fluid of the adjoining particle towards itself, and repel the fluid like to it (as the moon draws the water in the earth under herself), and the second atom will thus be polarised by the inductive power of the first. This second atom will have a like action on the third, and polarity will thus be propagated like waves. Each excited pole will cause an *opposite* excitement in the adjoining side of the next atom, and a *like* excitement in the far-off side.

38. This hypothesis serves in some measure to represent or express the actions which are seen to occur; it cannot be said at all to explain them.

FRICTIONAL OR TENSION ELECTRICITY.

39. The electricity of Friction or Tension is the excitement that first received the name of electricity; and it is still called Common Electricity. It is usually developed by means of friction, although there are many other sources of it. Its most appropriate name is Tension Electricity—meaning that it possesses a high degree of tension, or tightness, or energy, so that when it is discharged, it strikes a sudden and powerful blow on whatever comes in its way. It agrees with magnetism in being a permanent and self-sustaining excitement; it is contrasted with magnetism in its being producible on almost all substances, and in its being very liable to be discharged or reduced to neutrality.

40. If we take a stick of sealing-wax, and rub it with a dry woollen cloth, we shall find that it has acquired the power of attracting light bodies, such as little bits of paper or fine dust. In its ordinary condition the wax has no such property; the attraction is caused solely by the excitement of the rubbing. A piece of amber (*electron*), or any resinous body, will show the same phenomenon. A glass rod, well dried and rubbed with a piece of silk, will in like manner become attractive for light bodies.



41. The entire range of this action is best seen by suspending a feather, or a pith-ball, by a silk thread, on a stand such as that in the figure. The lightness and mobility of the ball (*b*) make it a very delicate test of the existence of attraction. If, then, we bring the rubbed wax (*w*) near the ball, it will be attracted; but on the instant of touching, the attraction seems to cease; the ball drops away from the wax and flies off, and is now repelled by it; so that if we bring the wax near the ball, the latter moves still farther away. The contact brought about by the attraction at first has led to the communication of something to the ball, which causes it to be actively repelled by the wax. A rod of glass will exhibit the very same train of actions—first attraction, then contact, and lastly active repulsion.

42. If, now, we compare the effects of wax and glass on the same ball, a new distinction appears. Let the ball be acted on by the excited wax, or be attracted, touched, and finally re-

pelled. While in this state of *repulsion* by the wax, let an excited glass rod be brought near it—it is instantly *attracted* by the glass, brought into contact, and then repelled. If the wax be now brought near, the ball will be attracted once more; so that there is evidently an opposition in the characters of excited wax and excited glass; what the one repels, the other attracts, and what the one attracts, the other repels. They are like the opposite poles of a magnet. The friction thus developes a force which is polar in its nature. The discovery of the difference between wax and glass has led to the belief in two kinds of electricity—the one called *resinous*, from its being the excitement of wax and resinous bodies; the other *vitreous*, or the excitement of glass.

43. If we now take two pith-balls, and suspend them together or near one another, and apply the excited wax, we find both attracted, sticking for an instant on the wax, and then driven off, and both held at a distance by repulsion; but besides being repelled by the wax, we see that they are also repelled by one another. The very same happens with a glass rod, or any electrified substance; so that when two bodies have touched one and the same excited body, they acquire a mutual repulsion. It is now plain that the balls have received some influence by touching the wax, for after it is taken out of the way, they continue actively to repel one another. From this we infer that a body electrified by friction can communicate its excitement to another body by touching it; so that the excitement does not remain fixed in the place where it was produced, but can run along from one surface to another. This conveyance from place to place is called *conduction*. While the pith-ball lies on the surface of the wax, it receives a portion of the wax's excitement upon its own surface; and when two balls have each acquired excitement in this way, they show it by repelling each other, just as the wax itself repels one or both of them. It is manifest that the electricity that passes upon the pith-ball from the wax is of the same kind as the wax itself possesses. This can be still better proved by comparing, as follows, the wax with the opposite substance, or with the glass rod.

44. If the glass rod is used exactly as we have described in the case of the wax, the same thing will happen by means of it: the two balls will be both attracted, then both repelled, and when the rod is withdrawn they will remain repelling one another. But let us next act on one of the balls with the wax, and on the other with the glass, until the one ball is seen actively repelled by the former, and the other actively repelled by the latter. In this state let the balls be brought

within a little distance of each other; they instantly attract and fly together. Thus when both balls receive excitement from one substance, they repel, when they receive excitement from opposite substances, they attract, one another. The wax by touch gives its resinous excitement, and the glass a vitreous excitement; and the opposition of polarities thus created causes attraction, as in the magnet.

45. We have therefore the following general results arising from the rubbing of substances:—

1*st*, A great number of bodies, by being rubbed, acquire an electrical excitement, shown in attracting other bodies. Both the substances rubbed and the substances attracted may be as various as possible; showing that the property is not special and confined to one or a few substances, like magnetism, but universally diffused.

2*d*, This excitement can be communicated by touch to other bodies; showing that it does not remain attached to the excited particles, but may run along a surface and seize other particles, and give them the same power as if they had been themselves acted on by the rubbing. This property of *conduction* is not seen in magnetism.

3*d*, There are two opposite kinds of the excitement; exemplified, the one in wax, and all resinous bodies; the other in glass (vitreous).

4*th*, When two bodies receive the same excitement, they repel each other; when they receive opposite excitements, they attract each other. This is the law of magnetic excitement also.

46. It is found that the force of the attraction, or the repulsion caused by electricity, is inversely as the square of the distance; whence it resembles not only magnetism, but gravitation, heat, light, and sound.

47. It is necessary to state here the explanation given by Franklin of these phenomena, as it led to the adoption of the terms *positive* and *negative*, instead of vitreous and resinous, to express the two electricities. He imagined a fluid pervading all matter, strongly self-repulsive like a highly-elastic gas, and spreading itself as wide as it possibly can. This great repulsiveness is, however, modified by its second property, which is an energetic attraction or adhesion to all material bodies, so that each substance contains a quantity of fluid pervading it throughout, and firmly bound to each atom. In ordinary circumstances it is in a state of rest or equilibrium, or so counteracted by itself that it makes no motions of any kind; but when two bodies are rubbed together, the equilibrium is disturbed, one of the bodies acquires more than

its natural share, and the other less: the one contains, as it were, condensed fluid or ether; the other rarefied fluid. But this forced inequality cannot last: the condensed fluid tends to rush towards the rarefied portion, and in so doing, drags with it the substance it resides in, so that there is an attraction of the bodies themselves when their containing fluids are of unequal strength. Hence the tendency to come to an equilibrium, joined with the adhesion to the particles of bodies, brings on the attraction which we see. On the other hand, if two bodies have both an excess or a condensation of the fluid, their repulsion will be above average, and they will move away from one another.

48. This hypothetical assumption is not sufficient to explain all the phenomena; but it agrees with some of the most prominent of them, and brings out an additional fact, not apparent from any of the foregoing experiments, but completely established by other experiments, which we shall state as the fifth general law of electrical excitement.

5th, When a body is electrified by being rubbed, the rubbing body also receives an equal and opposite excitement. Thus the cloth that rubbed the wax is electrified as much as the wax, but with the opposite kind—that is, of the same kind as glass acquires. So the rubber of the glass rod is resinously electrified.

49. Now, according to Franklin, electrical excitement is the same as an excess or a defect of the electrical self-repulsive ether; and accordingly he calls the one excitement *plus* or *positive* electricity, the other *minus* or *negative* electricity. These terms are found to be so appropriate that they have been retained, and extended to all the *current* electricities to be afterwards described. The electricity produced on glass is what is chosen as positive; that on wax is therefore negative. It is therefore to be distinctly bórne in mind that

Glass or vitreous electricity is *positive*.
Wax or resinous electricity is *negative*.

When a pith-ball touches sealing-wax, it is *negatively* electrified; when it touches glass, it is *positively* electrified. The cloth which rubs wax is positive; the cloth which rubs glass is negative. Positively electrified bodies repel each other; negatively electrified bodies also repel each other; a positive body and a negative attract each other.

CONDUCTORS AND INSULATORS.

50. Although the word *conduction* is used to express the travelling of electrical excitement from one surface to another,

the passage of electricity is very different from the passage of heat, also expressed by conduction. Heat is conveyed slowly from one portion of a mass to another, or from one body to another in contact with it; electricity passes quickly, and sometimes, we may say, instantaneously. Heat penetrates the interior, electricity travels on the surface. Electricity is not radiant like heat; it does indeed influence bodies which are at some distance, but the influence is quite of another kind from conduction, or from what passes by touch or contact.

51. But although conduction is a general property of the electrical excitement, it is very different for different bodies. On some surfaces the excitement runs from end to end with such quickness that no sensible time elapses; on others it travels slowly, so that a rod might be strongly excited at one end, and yet remain a long time neutral at the other end; such a body would be called a bad conductor. But the word *insulate* is used as the opposite of *conduct;* when a substance retains the electricity, and resists its passage from place to place, it is said to be an *insulator;* the electricity is cooped up there as in an *insula* or island.

52. The substances we have mentioned as convenient for producing electricity—namely, wax, resin, amber, glass, &c.—are all bad conductors, or insulators. The excitement on a stick of wax remains almost on the very spots which are rubbed; it does not pass along the surface except in a very small degree. The same is true of a glass rod, but not to the same extent; the glassy surface resists the passage sufficiently to be called a good insulator, but it does not resist so well as the wax. This property of insulating the electricity is essential to the success of such experiments as we have described with these substances: had the excitement run freely over the surface of the rods, it would have passed away by the hand, and disappeared as fast as it was produced, and the attractions would not have occurred. If the rods were wet, the effects would not be seen; for water in the smallest film is a good conductor, and would carry away the excitement, so that we would not know that any had been really produced.

53. The substances which form the best conductors are the metals. Although unequal in this respect, every one of them is a good conductor; so much so, that no perceptible electricity can remain on any surface, if there be a metal in contact with it and connected with the ground. The following table exhibits a series of bodies in the order of their conducting power: those at the top are the best conductors, those at the bottom the worst conductors, or the best insulators. Read from above downward, it exhibits the order of conducting power; from

below upward, it shows the order of insulating power; so that we can give it the one title at the top, and the other at the bottom:—

CONDUCTORS.

Metals.
Charcoal in its various forms.
Fused chlorides, iodides, and salts generally.
Strong acids.
Alkaline solutions.
Water.
Alcohol.
Damp air.
Vegetable bodies.

. . . .

Animal bodies.
Spermaceti.
Glass.
Sulphur.
Fixed oils.
Turpentine.
Resins.
Ice.
Diamond.
Shell-lac.
Oxalate of lime.
Dry gases.

INSULATORS.

54. It will thus be seen that *charcoal* stands next to the metals; but this holds only of its pure forms, such as plumbago and well-prepared wood charcoal. In coal there is a mixture of oily and pitchy matter, which lowers the conducting power, because these substances stand low in the table. *Fused salts* are good conductors, and next to them salts not fused. *Acid* and *alkaline solutions* are better than *water*. When *vegetable* and *animal bodies* are spoken of as inferior in conducting power to water and alcohol, it is to be understood that they are quite *dry*. Living vegetables and animals are always moist, which will give them almost the same conducting power as water. The best insulators are seen to be the *dry gases*; that is, gases free from steam and vapour. *Water* is a good conductor only in its liquid state; *ice* stands low; and *steam* is not a conductor, but it is so liable to deposit water or dew on the surfaces of bodies, that its presence is generally adverse to insulation. *Shell-lac* is very much used as the best practical insulator; it belongs to the class of resinous bodies, but excels all the others of its kind in this peculiarity. *Glass* stands much below the resins in insulating power, and it is surpassed by sulphur; but on account of its

hardness and strength, it has very frequently to be adopted as an insulator.

55. It is convenient to draw a line in the above table at the place where, for practical purposes, conduction ceases and insulation begins. This line is taken between vegetable and animal bodies: a dry vegetable substance, such as a piece of wood or a linen thread, is a conductor, though an imperfect one; a dry animal substance, as a silk thread, is reckoned an insulator, and used as such. The farther we go from these on either side, the respective peculiarities become more intense and decided. For good conduction, a wire of some metal, such as copper, is used; for good insulation, glass, or wax, or shell-lac, may be chosen. But the very best insulators are made conductors by being damp: hence dryness of surface must be carefully attended to. An electrical eel, brought to this country some time ago, was killed by a water-rat in spite of its electric discharges; which, though sufficient to stun very powerful animals, had no effect on the rat, whose fur is unwetable by water, and therefore, as a dry animal substance, proved a good insulator.

56. The substances presented in the table are merely a selection from the general mass of existing substances. Every body in nature is either a conductor or an insulator of electricity; but the foregoing list will suffice to show with what other properties a conducting or insulating power is usually combined. It is evident, for example, that the gaseous state tends strongly to insulation; that bodies abounding in combustible material, such as the resins, are insulating; that the presence of water always causes conduction; and so on. The character of a very wide range of substances is determined since the rank of metals and of vegetable and animal bodies is ascertained.

57. It was formerly considered that the insulators were the only bodies that electricity could be excited on; hence they were also called *electrics*, while the conductors, such as the metals, were called *non-electrics*. But this supposition is false. The metals are excitable by friction the same as the resins; but from their being good conductors, the electricity is apt to disappear from their surface as fast as it is formed. It is possible, by proper insulation, to make them electric, as well as sealing-wax or glass. In the electrical machine, the electricity is produced by the rubbing of a metallic surface on glass. The distinction of electrics and non-electrics, therefore, is no longer admitted.

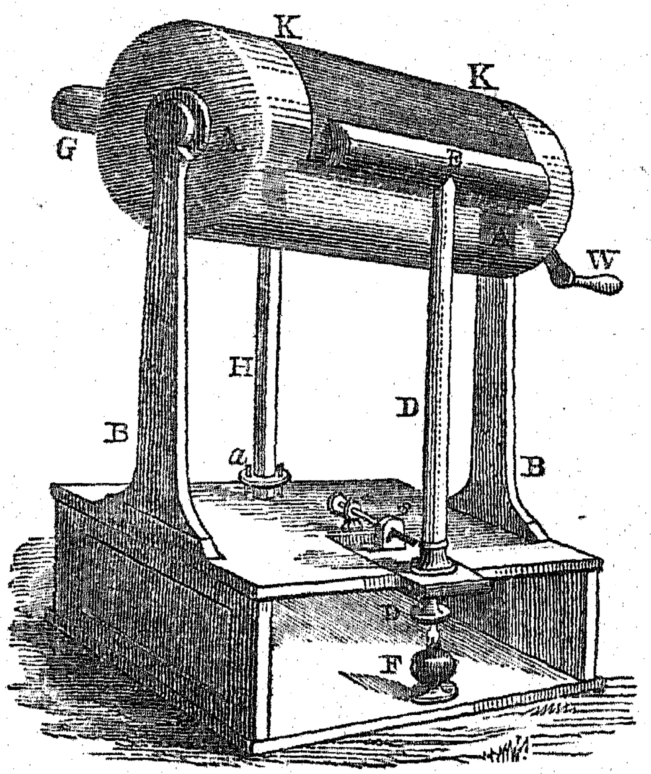
58. The earth is considered the general reservoir of electricity: whenever any excitement is connected with the ground

by a good conductor, it passes thither, and is lost by dissipation, like a wave spreading out on a boundless sea. The earth is generally neutral, or very slightly charged; and electricity of high tension will always run towards a body with either no charge, or with a feebler charge, and still more with an opposite charge. If the earth were negatively electrified, positive electricity would run towards it with still more energy than if it were neutral; whereas negative electricity would not run thither, unless its tension or strength were greater than the tension of the earth's charge. It is in all cases necessary to place insulators between an electrified body and the ground, in order to retain the charge.

59. When an electrified surface, or an electric charge of any kind, has two connections with the ground, or with neutral surfaces where it can spread, it always passes by the best conductor, even although this should be by far the longest path. Thus a metallic rod would be preferred to a line of water, water to dry wood, and wood to glass.

THE ELECTRICAL MACHINE.

60. In order to procure electricity in large quantities, and of great intensity, a rubbing machine is constructed, called the Electrical Machine. Its essential parts are *a cylinder of glass* mounted on an axle on which it may be turned, a *cushion* covered with a metallic paste, and a *metallic cylinder* to take the electricity off from the glass. The figure represents such a machine. A A is the glass cylinder revolving on an axis in the two supports B and B, which are either of wood or glass. E is a cylinder, carrying the cushion that rubs on the glass. This cushion is commonly separable from the cylinder, and when placed in it, rests on a spring, which keeps it close to the glass during the friction. The



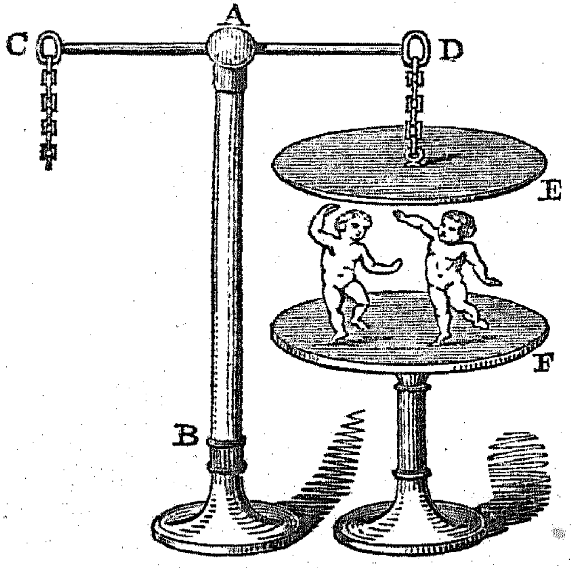
cylinder E has a metallic surface of brass or tin, and it is supported on a pillar D, which is an insulator made of glass. On the other side of the glass cylinder is the metallic cylinder G, destined to receive the electricity evolved on the former. It does not of itself rub on the glass, but it is armed with a row of brass points, which almost touch the excited cylinder, and which are specially adapted to carry off the electricity, and spread it over the metallic surface. This cylinder is called the Prime Conductor, or first receiver of the excitement, and it is supported by a glass pillar, H, in order to be insulated. As the electricity of glass is positive, this cylinder must always receive positive electricity; hence it is called the Positive Prime Conductor. Since the cushion cylinder gets itself charged with negative electricity, it is called the Negative Prime Conductor. The base of the pillar supporting the negative conductor is movable by a screw *s s*, to regulate the pressure of the cushion. A flap of silk (K K) is fastened to the upper edge of the cushion, and covers the upper half of the cylinder; this may both increase the friction given to the glass, and help to retain the electricity on the surface till it go round to the points on the prime receiver. The surface of the cylinder and of the insulating pillars must be kept warm and dry during the working of the machine; and for this purpose a permanent heating body is sometimes kept near, such as an iron heater or a lamp (F) applied to the hollow (D) of each glass pillar. Although the cushion cylinder is on an insulating stand, it is not generally insulated when the machine is worked; insulation is used merely for certain special experiments. Accordingly, it is usual to connect the negative cylinder with the ground by a chain. If it were not so connected, it would become highly charged with negative electricity, and resist the further disengagement of the excitement.

61. The operation, then, consists in turning the cylinder rapidly by the handle W. Its surface is rubbed hard on the metallic paste, which the cushion is smeared with, and electricity is evolved of both kinds. The positive excitement appears on the glass, and is carried round and taken off by the points of the prime conductor, and there accumulated, being cut off from all conducting communication with the ground. The negative excitement is given to the metallic coating of the cushion, and thence to the whole of the negative cylinder; but for the sake of getting additional excitement from the machine to the other side, this is carried to the earth by the chain.

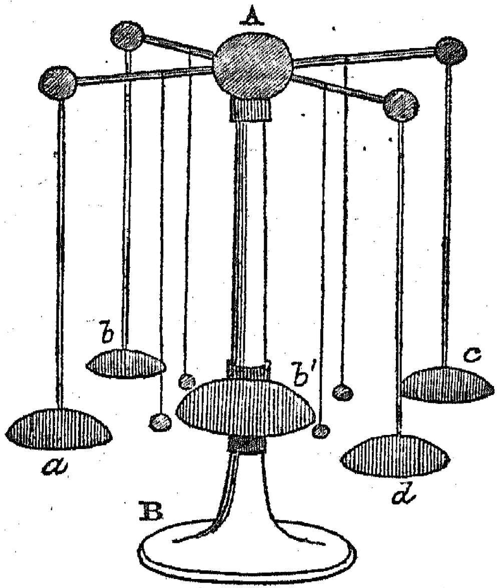
62. While the positive prime conductor is thus receiving a constant stream of positive excitement, we may derive from

it electricity for any experiments that we desire to make, or we may observe upon itself the various properties of electrical excitement. Such experiments as we detailed at the outset can now be made with far greater effect than with glass rods or sealing-wax; the attractions and repulsions will be much more powerful. Feathers, pith-balls, and the like, will be attracted and repelled with rapidity and vehemence. And by means of metallic rods, electricity can be conveyed to any surfaces we please at any distance.

63. A great number of striking and beautiful experiments can be made by electrifying bodies, and making them display the attractions and repulsions caused by the electricity. For example, in the figure, B is an insulating stand formed of a glass pillar, A is a brass knob at the top of the pillar, and through this nob runs the brass rod C D, which suspends by a metallic chain the metallic plate E. A second plate F lies a few inches beneath the first, and rests on a stand which is not insulated. A few light figures of pith or other substance are laid upon the lower plate, and the end of the rod C is brought into connection with the prime conductor of the machine, either by touching it, or communicating by a chain or rod, or by being so near, that the electricity can fly off to it in sparks. If the machine is now worked, and electricity conveyed off to C, it will run along C D, and down to the upper plate, and remain there, since it cannot go down by the glass pillar to the earth. The upper plate, in consequence of its charge, will attract the figures from the lower plate, and make them fly up to it; but as soon as they touch, they will become themselves electrified by conduction, and be repelled or thrown down from that plate; but they no sooner touch the lower plate, than they give away their excitement to it, whence the charge passes off to the ground, and they are neutral as before. The upper plate now attracts, and electrifies, and repels them again; and they move up and down a second time, and discharge their excitement to the lower conductor, and are ready to be attracted upwards a third time, and so on. In short, so long as the upper plate is electrified, they are kept dancing up and down; hence the name *Dancing Figures* is given to the apparatus.



64. The *Electrical Bells* is another apparatus for showing the same effect. The stand B carries upon it at a little height a bell *b′*, and above the bell a glass insulating rod terminating in the brass knob A. From A proceeds four brass rods, and from their extremities are suspended by brass rods or chains four bells *a*, *b*, *c*, *d*, hanging on a level with the ball *b′* on the pillar. Four brass balls are suspended by silk threads from the arms running out from A, so as to hang between the outer bells and the central one. Electricity is then conveyed to the central knob, or to any of the arms, and runs over the whole of the arms and the outer bells, but it is prevented by the glass pillar from passing to the middle bell, and by the silk threads from passing to the brass balls. The outer bells are therefore highly charged with the electricity of the positive prime conductor, and each attracts the ball next it. The balls move up, therefore, and strike the bells; but no sooner touch them, than they are repelled, and fly in the direction of the central ball; which, being neutral and uninsulated, takes off their electricity, and with it their repulsion from the outer bells; so that the instant they strike upon the neutral centre, they are again attracted to the electrified bells, and immediately repelled as before. Thus, by incessantly swinging between the two, they keep up a tinkling as long as the electricity continues.



65. Another set of experiments on the same principle is made by feathers, heads of hair, or like bodies. When these are electrified, the repulsion that bodies in the same state always manifest, causes the hair to bristle up, and spread itself out as far apart as possible.

66. It can be easily proved by the machine, that while the glass cylinder acquires positive electricity, the rubber becomes negative. For this purpose the cylinder containing the rubber is insulated by removing the chain usually attached to it, and the positive conductor is connected with the ground. In this state the conductor that has the rubber will be excited, and its excitement can be turned to the same account as the other in such experiments as the above. But to test its character, we may use a suspended pith-ball and a piece of sealing-wax, which we know when rubbed to be negative. Let the

sealing-wax attract the pith-ball, and electrify it with its own kind, so as to repel it. Let the ball now approach the electrified conductor, which ought to be feebly charged; and it will be repelled by it also, showing that the electricity of this conductor is the same as that of the wax, or negative. If the ball had been excited by touching a glass rod, it would have been attracted by the cushion conductor. Such experiments will not succeed if the conductor is powerfully charged, because in that case the trifling excitement given by a piece of wax is completely overwhelmed by the conductor's excitement, and the ball is acted on as if it were neutral. A piece of excited wax, or any resinous surface, serves on all occasions to test which of the two electricities is produced.

67. The metallic paste smeared upon the cushion (a hair-cushion covered with chamois leather) is what is called an *amalgam;* that is, a combination of mercury with other metals. If a bar of tin, lead, or zinc, or any metal, be dipped into a vessel of mercury, the mercury will partially dissolve it, like water with a salt. A solution in this way of any other metal in mercury gives an amalgam. The mixture used for the electrical rubber is one part of tin and two of zinc to six of mercury; but different proportions have been used by different experimenters. With the addition of so great a quantity of solid metal, the mercury loses its extreme fluidity, and becomes viscid and pasty, approaching to an incoherent soft powder. It is spread on the cushion with the blade of a knife, and requires to be renewed from time to time; for besides being dissipated by the action of the machine, it seems to undergo some chemical or other change that gradually takes away its power of exciting the electricity.

68. Another form of the electrical machine, more powerful than the one just described, is what is called the Plate Machine; that is, instead of a cylinder, a flat circular plate is used. The cushion must then be double, so as to hold the edge as between one's finger and thumb; and the other parts must correspond to the shape of the glass. Two rubbers and two sets of points are commonly applied to the plate's edge, dividing it, as it were, into four quarters. The objection to such machines is their liability to crack, by the heating that all machines must undergo to make them thoroughly dry before being wrought. But a cylinder machine can be much improved in power by attaching two rubbers to the cylinder, one above and the other below, and enclosing both sides of the cylinder with rows of points, and also by reducing the thickness of the prime conductor (which must have the shape of a spur whose arms contain the two rows of points) to about an

inch. Such a machine has been constructed by Mr Straton of Aberdeen; and it yields many times the quantity of electricity that would be given by a machine of equal size made in the ordinary form.

69. A machine of great power has been constructed, which receives the name of Armstrong's Hydro-Electric Machine. It was observed by Mr Armstrong, that a jet of steam rushing out from an iron boiler, made the boiler give off electric sparks, showing that it had been electrified by this action. Accordingly, iron cylinders have been formed like the boilers of steamboats, and mounted with tubes for the escape of the steam in the form of jets. The steam is raised to a pressure of two or three atmospheres before the tubes are opened. It is then allowed to rush out in a row of jets, and in doing so it communicates *negative* electricity in great quantity, and of a very intense kind, to the whole outer surface of the boiler, while it is itself positively electrified in an equal degree. The boiler being supported on glass pillars, in order to be insulated, becomes so intensely charged that, if not relieved, it darts off sparks to great distances. No rubbing machine can equal such an apparatus in power.

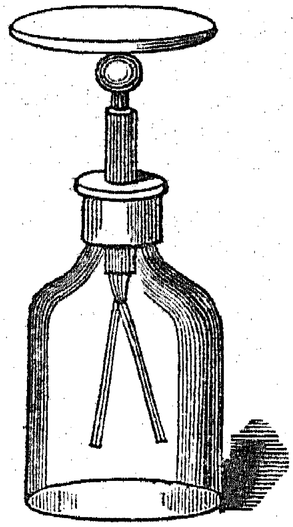
70. The mode of action in this machine has been thoroughly investigated and explained by Faraday. He has shown that the electricity arises from the friction of water globules against the edge of the steam-holes. When the steam rushes out at high pressure, it carries a shower of water particles with it, and these act as a rubber upon the metallic surface of the boiler; and the strong friction between water and iron is the source of the electricity. If the steam is dry—that is, if it is perfect steam, or the true elastic gas of water, and free from cloudy or watery particles—it produces no excitement whatever. If atmospheric air, or any other dry gas is used, there is no electricity excited; and it is completely proved that a gas can in no case serve as a rubber to evolve electricity. But if the gas carry with it a shower of particles either *solid* or *liquid*, the surface that it rushes through becomes electrified, and the solid or liquid particles acquire the opposite excitement. It depends upon the substance used what is the kind of electricity given to the metal. The iron boiler is made negative by the water particles in the steam current; but if we substitute for water oil of turpentine, olive oil, resin, or other similar bodies, the solid rubbed by them is positive and the jet negative. Either steam or dry air may be used to carry the powder, the gas having no action but to sustain the rubbing stream. The action ceases if the water-drops contain any trace of acid or salt, which would render them

much better conductors of electricity than drops of pure water. It is from its being too good a conductor, that a metal cannot be electrified by ordinary rubbing, like a piece of amber or wax. But the rapid rush of watery particles succeeds in charging even a metallic surface. If, however, the water is rendered too good a conductor, by an acid or a salt being dissolved in it, the difficulty of keeping the electricities apart is rendered so much greater.

ELECTROSCOPES AND ELECTROMETERS.

71. An instrument for *showing* the existence of electrical excitement is called an Electroscope; an instrument for not only proving it to exist, but also *measuring* its strength or tension, is called an Electrometer. There are many instruments of both kinds:—

72. A pair of pith-balls hung together serve to indicate the presence of electricity. If they are brought into contact with an excited surface, they become both charged with the same kind, and repel each other. Of course, if the surface touched is neutral, there will be no action.

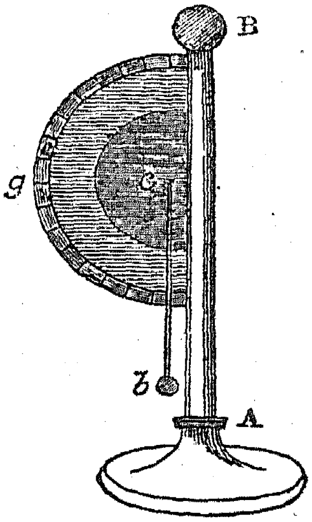


73. The Gold-Leaf Electroscope is on the same principle, but far more delicate. It is represented in the adjoining figure. A glass vessel has inserted in it a metallic rod terminating in two gold leaves, and surmounted by a metallic plate. The rod passing through the neck in the bottle is covered with shell-lac varnish, and surrounded besides by a glass tube. A very small degree of excitement communicated to the metallic plate will cause a divergence of the gold leaves. To ascertain the kind of the electricity, it can be compared with the influence of sealing-wax.

74. Both the pith-balls and the gold-leaves serve as electrometers to a certain extent; for in proportion to the strength of the charge will be the distance of the repelled balls or leaves. And if we estimate this distance by a graduated scale, we shall have a measure of the electrical tension. But there are many other arrangements for measuring the excitement, such as the following:—

75. The Quadrant Electrometer is represented on next page: A B is the stand, and *g* a semicircle of ivory, graduated according to the divisions of a circle. From the centre *c* hangs a strip of cane, with a pith-ball *b* at its other end. If,

now, the stand is connected with an electrical surface, so as to be itself electrified, the pith-ball hanging by it will share in the excitement, and be repelled, and rise up the scale. The degree to which it ascends will be a measure of the strength of the electricity.



76. Volta's Electrometer is analogous to the gold-leaf apparatus; but instead of gold leaves, it has two straws hung from hooks at the end of the metallic rod. A scale is fitted up in the glass vessel to measure the divergence of the straws. This instrument is much more delicate than the quadrant electrometer.

77. For measuring very strong charges, an apparatus of a larger kind is made use of. Such is what is called the Balance Electrometer, where the strength is measured by the weight which can be overcome by the repellent power of an electrical charge. One end of a rod balanced on the middle lies upon another rod, both ending in balls or knobs; when an electrical charge is communicated to the apparatus, the two balls repel each other, and the end of the balanced rod rises. The weight which can be lifted up by the rising end is a measure of the strength of the charge.

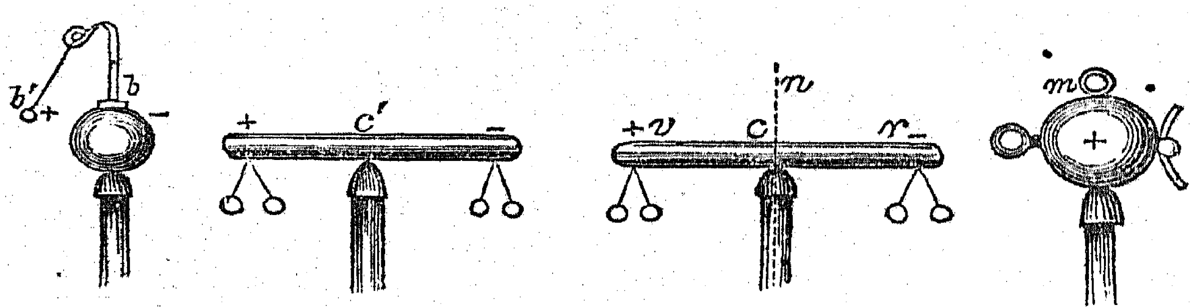
78. The Torsion Balance of Coulomb is a very important instrument, both in electricity and in other departments, for the delicate measurement of forces. A rod is suspended by a thread, so as to hang horizontally like the beam of a balance; and when this rod is acted on by any force, there is no resistance to overcome but its own inertia, and the twisting of the thread; the last is so very slight, that a large sweep of the rod takes place from a very faint action, and thus the minutest degrees of force can be measured and compared. Coulomb invented this instrument to investigate the law of electric force in relation to distance; and by it he proved that electricity resembled gravity and other central forces, and diminished as the square of the distance increased.

INDUCTION.

79. It has been seen that when electricity is evolved, both kinds are formed at the same time. The one of the two rubbed bodies has a positive charge, the other an equally strong negative charge. The same principle extends farther; we find that a charge cannot even exist on a surface unless there be on some adjoining surface an equal and opposite charge. Posi-

tive electricity cannot be insulated, and made to remain by itself; it will not pass into any situation where it cannot be accompanied with a counter charge of negative excitement. The polar character is rigorously sustained in frictional electricity, as well as in magnetism; we can no more have one kind of excitement alone by itself, than we can have a magnet all north or all south.

80. When a surface charged with electricity of one kind is in the neighbourhood of other surfaces, but not touching them, it communicates to them the *opposite* electricity. The apparatus best adapted for demonstrating this is a set of brass cylinders rounded at the ends, and placed on insulating stands.



Thus let *m* be the prime conductor of a machine; *c* and *c′*, two insulated cylinders laid end to end at a little distance from each other and from the conductor; and *b* a brass ball, with a pith-ball *b′* suspended to it. When the machine is wrought, the whole of the surface of *m* has positive electricity. Now the action of *m* upon the adjoining cylinder is such, that the nearest end *r* is electrified negatively, and the remote end *v* electrified positively. The cylinder has received no electricity by conduction; it has become polarised by induction, exactly as happens in magnetism. The middle *n* is neutral, and the two ends are charged with equal and opposite excitements. But this cylinder exerts its action on the second cylinder in the same way; the end of which next *v* is negatively charged, and the other end positively charged. The ball *b* also is affected by the positive end of the second cylinder, and made negative at one side and positive at the other, where it repels the pith-ball. Thus the prime conductor, without parting with any of its excitement by *conduction*, polarises a series of bodies by its *inductive* power. There is no limit to the number of bodies that might thus act on each other, except the tension of the conductor; but the action on each successive surface becomes gradually feebler.

81. If the remote end of one of the cylinders is connected by a conductor with the earth, the charge on that end passes off to the earth, and the opposite electricity spreads over the

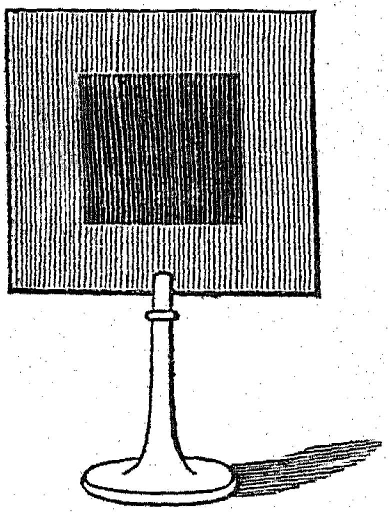
whole surface of the cylinder. Thus if the positive excitement of *v*, the far end of the first cylinder, were conducted away, the cylinder would possess all over a negative charge, as if it had been connected with the negative prime conductor of the machine. But if, on the other hand, without conducting off any portion of the induced electricity from any of the surfaces, we withdraw the prime conductor *m*, whose tension caused the succession of polarities, they all instantly return to their original neutral condition. The presence of the primitive source is necessary to sustain the action; and when this fails or is cut off, it is like the removal of a magnet from a soft iron bar—the temporary excitement ceases.

82. We may now understand why an electrified surface attracts a neutral or unelectrified body, such as a pith-ball. It is not that electricity causes attractions between excited and unexcited bodies, the same as between bodies oppositely excited; but that the pith-ball is first rendered opposite by induction, and attracted in consequence of this opposition. A pith-ball at a few inches' distance from an electrified surface, is charged with electricity by induction; and the kind being contrary to the kind of the surface, attraction ensues; when the two touch, they become of the same kind by conduction. The case of attraction by excited surfaces is the same as the magnet's attraction for iron; an opposite excitement is first communicated to the body, and it is then attracted. If a series of cylinders were electrified as above shown, they would all tend to attract each other by their opposite poles.

83. It is a fact only lately discovered, that neither the prime conductor of the machine, nor any surface whatever, can receive or contain electricity, unless there be other surfaces near to contain an opposite charge of the induced kind. Whatever bodies are in the neighbourhood, the walls and furniture of a room, &c. are made use of for this purpose, as well as anything that is casually brought near. If the surrounding surfaces are easily excited, and can take on the induced electricity well, the prime conductor of the machine, or any connected surface, may acquire a high charge; but if these surfaces are difficult to excite, if they are of the non-conducting kind, the prime conductor will receive only a feeble charge. The second pole is in this case not readily observable—it has a sort of irregular character; but decisive experiments were made by Faraday, which proved that where there is not a confronting surface for the induced charge, it is impossible by the most powerful machine to put the least possible excitement on any surface whatever. It had previously been shown, that if the outer surface of a hollow

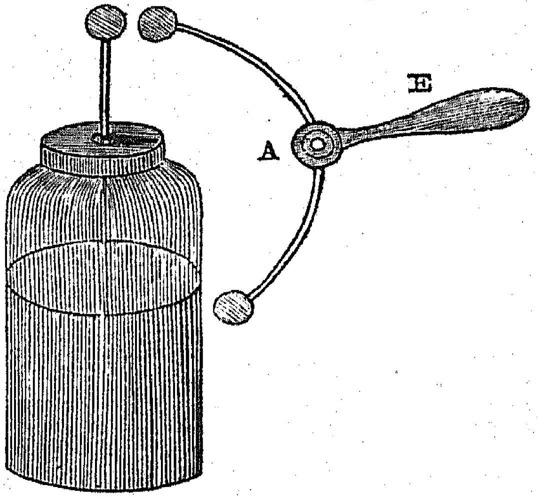
sphere were charged, no electricity would pass to the inside, although there were a free communication by holes; and Faraday put the thing to the test on a large scale by constructing an insulated room, which he went into with his electroscopes, while the outside was charged by a large machine; whereupon it was found that no trace of excitement appeared in the inside. The reason is, that there is not room in the interior of a continuous hollow surface for both excitements to exist apart, and yet confront one another.

84. There is a limit placed to the accumulation of electric excitement on any surface. But the better the opposition surface given for the induced electricity, the higher the charge that it is possible to communicate. Accordingly an apparatus was devised last century by a Dutchman of Leyden, thence called the *Leyden jar*, which completely suits the polar nature of the charge by providing two equal surfaces, held apart by an insulating medium, to receive both the primary and the induced electricity. The simplest form of this double-surface apparatus is a pane of glass, with a coating of tinfoil on each side, the coatings being equal to one another, and smaller than the glass, so as to leave an uncoated margin all round, as represented in the figure. If one of the coatings is connected with the machine, and positively charged, it will act by induction through the glass upon the other coating, and excite it in the manner already described in the case of the row of brass cylinders. The near or inner surface of the second coating will be made negative, and the other surface positive; and if the coatings are insulated, this state will continue. But if the outer side of the second coating is connected with the ground, and the positive induced charge taken off, the surface will have only a negative charge left corresponding to the positive charge of the first coating, directly derived from the machine. We have thus a true polar charge, a positive and a negative surface separated by an insulating medium. The excitement is now no longer *free*, but *fixed;* neither of the electricities will run off by touching the coating with a conductor; they are, as it were, held locked in one another, and the apparatus is almost like an unexcited body. There will be no attraction of pith-balls, because the electricity does not need surrounding surfaces to act upon by induction in order to maintain itself. A



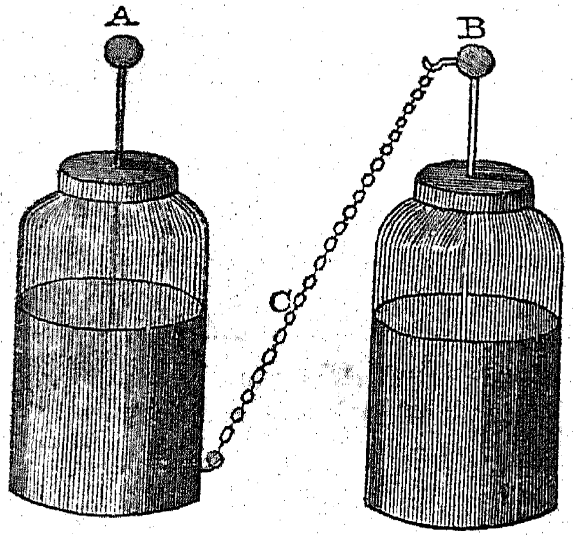
very high charge can now be administered, if we keep the outer surface of the second coating connected with the ground, while the first is connected with the machine. There being a proper surface for the induced excitement, the primary excitement can rise higher and higher; but it will not show its strength in the same way as on a single surface. The dead lock of the two prevents them from acting singly; and we hardly know of the accumulation that has arisen, till the two surfaces are connected by a conductor, such as a metallic wire; we then see a bright spark, and hear a sharp snap, as if a violent shock had been sent through the apparatus.

85. The Leyden jar is a glass bottle with two coatings of tinfoil, one outside and the other inside. The coatings do not reach to the mouth of the bottle, so that they leave a rim of naked glass. A plug is fitted tightly into the mouth, and covered with varnish, and through the middle of it a brass rod is passed, with a chain hanging to its lower end, to make a connection with the inner coating. The upper end of the rod is formed into a round knob. The figure represents the jar with the apparatus used for discharging it; which last is a glass rod E to hold in the hand, and two brass arms connected at A by a movable joint. Through these two arms the two electricities run to meet one another, when one end touches the outside of the jar, and the other comes near the knob connected with the inside. In using the jar it may be held in the hand, and the knob presented to the prime conductor of the machine; the inside thus acquires a positive charge, and induces a negative one on the near surface of the *outer coating* fronting it; that is, on the inside surface. The outside surface of the outer coating would then be positive; but it being in the hand, the positive electricity passes away, and leaves the outer coating entirely free for a negative charge, which it thus possesses, and thereby fixes the positive charge in the inside. The transmission of more electricity from the machine to the inner coating, induces more on the outer, till the jar is as highly charged as the strength of the excitement communicated can make it. If, now, we try the outside with a pith-ball or other electrometer, we find no sign of electricity; if we try the inside through the projecting rod, we find indeed a very feeble charge; but there is no appearance corresponding



to the actual excitement held by the two coatings. Let us next apply the discharging rod; and having touched the outside with one ball, let us approach the knob with the other; and while these are yet an inch or two inches apart, the two electricities will flash together with the usual spark and noise. The tension or strength of the excitement is shown by the distance that may thus be broken through by the attraction of the opposite states for one another; just as the strength of the excitement of the prime conductor of the machine is judged of by the distance that sparks will pass through to a conductor placed near.

86. The electricity driven off from the outer side of the outer coating by the induction, instead of being conveyed to the earth, may be passed to a second jar, and may communicate to it a charge by the same process as the first jar is charged. Thus, in the figure, let A, the knob of the first jar, be in contact with the prime conductor of the machine, and let the outer coating be insulated, by resting the jar on a plate of glass or other insulating substance. A chain C passes from this outer coating to B the projecting rod of the second jar, whose outside communicates freely with the ground. By working the machine, the inside of the first receives a positive charge, which excites a negative state in the outer coating, and in consequence drives off positive electricity by the chain C to B, and thence to the inner coating of the second jar. A second induction now takes place; and in order to render negative the outer coating of this jar, positive electricity must be driven off to the ground. Thus both jars are charged, and in the same way a succession of jars might be charged; but the second is weaker than the first, and the third than the second, and so on, until at last the excitement would be imperceptible. After being charged, the jars may be disconnected, and each discharged by itself. It happens in this case, as with the cylinders, that one polarity is but the commencement of an endless series of polarities which can be traced to a certain distance, growing weaker and weaker at every step.

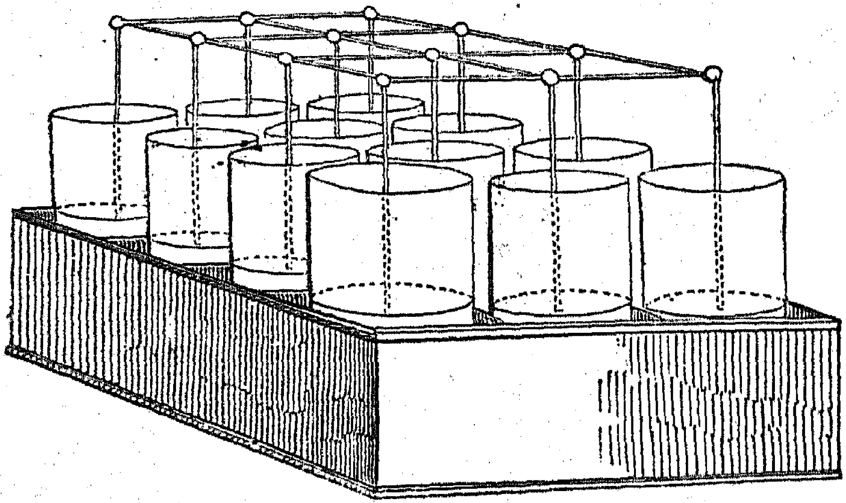


87. The strength of charge which can be communicated to

a Leyden jar depends upon the thinness of the intervening glass. The whole *quantity* of the excitement will of course be greater as the jar is larger in size; but its tension, strength, or intensity increases as the thickness of the glass is reduced. The glass offers a certain resistance to the induction, and a certain degree of tension is expended in overcoming this intermediate resistance. The particles of glass are themselves successively polarised, and it is only the surplus of the inductive power that reaches the other coating. Hence the charge on the second coating is never equal to the charge on the first; and consequently the reaction of the second does not suffice to fix the whole of the excitement of the other. This is the reason why a certain amount of free electricity may be detected in the coating that was connected with the machine. If, however, this free electricity is taken off, the remaining quantity will become insufficient to support and fix the whole of the induced charge in the other coating, and a small portion of its electricity will now be rendered free, and become sensible to an electrometer. Should this also be conducted off, the inner side will next show a surplus; and by touching the two sides alternately, the whole charge may at last be taken off, from this constant necessity for there being a surplus on one side to fix the entire charge of the other. The thickness of the glass gives rise, besides, to what is called the *residual* charge; for after discharging a jar, if we apply the rod again, a second discharge of a feeble kind will be observed. The first discharge neutralised the electricities of the metallic coatings; they being good conductors, their portion ran off first, and came together before the excitement of the glass had time to go off; and this remaining excitement furnishes the second discharge. There must be a limit to the thinness of the glass of the jar; for the electricity in polarising its particles evidently tends to tear them out of their natural cohesive position, and to join them together by new sides, corresponding to their electric poles. When the strength of the excitement comes up to a certain point, it forces its way through by making a hole in the glass. Jars are often pierced in this way and rendered useless by the violence of the polar coercion of their particles overcoming their cohesion.

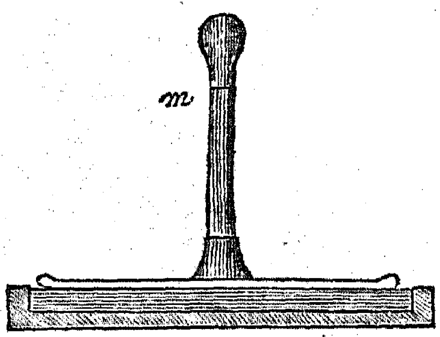
88. In order to accumulate electricity in great quantity, a series of jars are joined together, forming a *Leyden battery.* All the insides are connected by joining their projecting knobs together, and the outsides are connected by passing wires round them from one to another, or resting them all in a continuous metallic bottom. The principle of the charge is the very same as for a single jar; and the effect is nearly what

would follow from one enormous jar whose extent of coatings is equal to the sum of those which constitute the battery.



89. The insulating substance which separates two conducting surfaces, and enables them to sustain opposite states, is called by Faraday a *Dielectric.* All insulators are dielectrics, and the best insulators are the best dielectrics; for in as far as the dielectric is a conductor, it allows electricity to pass through in its own kind to the opposite surface, and thus discharges instead of charging the apparatus. As the glass of the Leyden jar is not a perfect insulator, but admits a very slow conduction of electricity, the charge necessarily decays, and becomes at last extinct. With sealing-wax or shell-lac the insulation would be more perfect, and the induction better sustained.

90. The action of bodies in the capacity of dielectrics teaches us the cause of their being insulators or non-conductors. Electricity passes through bodies by polarising their particles one after another; but in a good conductor the polar state is very readily induced, and exceedingly little inductive power is expended in bringing it on. Thus suppose the first particle becomes positive on one side, and negative on the other, it finds the second so easy to induce into a positive and negative state in its two sides, that without any loss of tension or time it polarises it; and in the same manner the negative end of the second renders positive the adjoining end of the third and the further end negative. Conduction is supposed to be nothing but a series of inductions; but these in some bodies are easily effected, in others with difficulty.



91. The *Electrophorus* is a very useful piece of electrical apparatus, depending upon induction. It consists of a plate of metal, covered, but not to the edge, with a plate of resin, which is poured on it and spread out in the melted state. On the cake of resin is

placed a second metallic plate having an insulated handle (*m*). If the resin be excited by rubbing, it will have a negative surface; and by laying on the cover, it will be electrified by the contact; the lower surface lying on the resin will be positive by induction, and the upper surface negative. If we touch the latter with a conductor, such as the finger, its negative charge will be taken off, and positive excitement diffused over the whole. By this apparatus a small positive charge can be easily obtained at any time.

92. The *Condenser* of Volta is an instrument intended to accumulate electricity, when of a very feeble strength, such as what arises in chemical actions. It is analogous to the Leyden jar, or rather to the coated pane of glass. It consists of two metallic plates placed on one another, with a very thin layer of gum-lac varnish between them. The thinness of the gum-lac, which serves as the dielectric, allows the induction to pass through, even although the excitement be very feeble; and therefore there can be an accumulation of weak electricity in the same way as the Leyden jar accumulates intense electricity. The condenser serves as an electrometer and electroscope, to attest the presence of excitement when too faint to show itself without accumulation.

93. When a single surface, such as the prime conductor of a machine, is charged by the help of the surrounding surfaces which serve to sustain its inductive charge, the intervening air is the dielectric; but this dielectric is easily overcome or ruptured, so that a discharge can take place through it at great distances. Thus if we hold our knuckle within an inch or two of the conductor, when the machine is at work, the hand serves as one of the random surfaces for the conductor to exert its induction upon, and becomes strongly negative, and the whole intervening air is polarised like the glass of the Leyden jar; but the air very soon gives way, and allows the opposite excitements to flash together in a spark. The more rarefied the air, the greater the distance that sparks will go through from one surface to another.

94. In the case of an excited single surface, it is found that unless it be a ball, the excitement is not equal on all parts of the surface. The prime conductor is generally a cylinder rounded at the ends into hemispheres, and the electricity is always stronger on the ends than on the body of the cylinder. If we take a large globe and a small one, and join them together by a rod, and pass electricity upon them, the charge will be most intense in the smallest. If the one have four times the surface of the other, the excitement of the large one will have only one-fourth of the strength of the excitement in the

small. Whenever a surface approaches to a point or an edge, the intensity proportionally increases. The cause of this unequal distribution is found in the theory of induction:—

We have seen that without a confronting surface to sustain an opposite charge, no body can possibly receive excitement; and the better provided a body is with a surrounding surface, the greater the charge that it can take on. Now, if we have two unequal balls in the same rod, their excitement depends upon the induction which they can exert on the surfaces about them; but the small ball being in the same room as the large, it has as good and extensive an inductive surface presented to it as the other. The two have unequal surfaces of their own; but they have the same confronting exterior surface in the walls and furniture of the room, and on this unequal proportion of surfaces depends their unequal capacity of being excited. If we had twelve balls of different sizes, all strung on one rod, and hung in the middle of a room, they would take on exactly equal charges; but if we had one ball in one room, and another in a different room of other dimensions and material, the charges would probably be unequal—the ball that found most facility in polarising the surfaces around it would take on the highest excitement. Now the rounded end of a cylinder is acted on like a small ball; for a larger surface is confronted with it than with an equal portion of the body of the cylinder. Suppose that, in the latter, four square inches had such a degree of curvature as to be opposed to one-tenth of the whole surface of the room, and that four square inches on the end made a hemisphere and confronted half the room (as the surface of a whole sphere would confront it all round), then the intensity on the end would be five times that on the middle. Accidental arrangements will make one part of a surface more intense than other portions equally well curved and exposed to surrounding surfaces; a metallic plate, for example, lying near one end of the prime conductor, will cause that end to bear a higher charge. A prime conductor of a machine working in a tinsmith's shop, would rise up to much more intensity than in an ordinary sitting-room. If a metallic cylinder were enclosed in a larger cylinder, it might be charged to a considerable degree; for this would be to make a perfect Leyden jar instead of the very imperfect way that the second surface is furnished by the walls and furniture of a room. The obstacle to the charge in this case would be the weakness of the dielectric; we would find it necessary to make the outer cylinder considerably larger than the inner, to allow some thickness to the intervening air, otherwise the electricity would break through and discharge itself.

95. We may now understand the cause of the very great intensity of the excitement at points and edges, and the tendency that the electricity has to pass off from them. A point is a very small surface, confronted with a very large exterior, and the extent of the induced surface allows a very high intensity to be attained. This intensity favours the discharge by increasing the action upon the dielectric of air, so that the electricity will pass off from a point to an opposite body at a much greater distance than it would pass through coming from the round bulge of a large blunt cylinder. Hence if a surface is armed with points, these will rob it of its excitement, and probably disperse it by their discharging force. A row of points are used, as we have seen, to take up the electricity from the cylinder of the machine; they being as powerful to receive excitement from a surface where it is in excess, as to pass it off to a surface where it is deficient. Of all single surfaces, a flat plate will take on the least intensity, and a sharp point the greatest. It is therefore necessary that surfaces which are intended to retain electricity should be well rounded, blunt, and smooth. And on the same principle it is requisite to keep the electrical apparatus free from particles of dust, which, like points, take on an intense charge, and fly away with a large share of the excitement.

THE DISCHARGE.

96. The Leyden jar is discharged by establishing a conducting communication between the two surfaces. But though this is essentially the manner of the discharge in all cases, it is usual to reckon three varieties of circumstances wherein it may happen, making, as it were, three different modes of annulling the excitement. These are called, 1*st*, The *conductive*, 2*d*, The *convective*, and 3*d*, The *disruptive* discharges.

1*st*, The *conductive discharge* is exemplified in the slow discharge of a Leyden jar through the glass, which, not being a perfect dielectric, allows of conduction to a small degree. Also when the air between an excited single surface and the surrounding surfaces is damp, the line of watery particles causes a slow communication by conduction, which gradually discharges the excitement. Again, if the uncoated glass of the Leyden jar is damp, a gradual discharge of the same kind takes place.

2*d*, The *convective discharge* is exemplified when pith-balls are attracted and repelled by a conductor, and then by touching some distant body lose their charge and become attracted again, as in the electrical bells and dancing figures. In this case the ball acquires by contact a certain amount of charge, which it carries off and communicates to the opposite induced surface, serving as a go-between to carry positive electricity to the negative surface, and negative electricity to the positive, and bringing about in this way a neutrality or equilibrium. Particles of dust tend to discharge surfaces by this process. In like manner particles of air are set in motion, and convey the electricity from one surface to its opposite. The intense action of points generally causes a current of charged air to run out from them, whose place is supplied by other air that acquires a charge in its turn, and is repelled like the previous portions. There is always a repulsion created by the passage of electricity from points, which can be made use of to create a rotatory motion, by making a sort of wheel with wire spokes, ending in points all bent inwards in one direction, and the whole revolving on an axis. The action is not unlike the force in Barker's mill. (See HYDRAULICS.)

3*d*, The *disruptive discharge* is the breaking or forcing of the dielectric, as when the glass of the Leyden jar is broken through. This arises when the twist given to the particles by their electrical state is stronger than their mutual cohesion. Glass is generally able to resist such a power, but the air offers very little resistance; hence disruptive discharges readily occur in it. This discharge may be exemplified by placing a card between one of the balls of the discharging rod and the coating of a Leyden jar, and passing the electricity through the card; the opening which it forces can then be seen, and from it we may form some idea of the action that has taken place. The hole is very small, such as would be made by a fine needle; but it is widened on both sides, as if the force had come equally upon it from each coating. Whenever any bad conductor, such as a piece of wood, is put in the way of a discharge, it is split up or pierced in the same manner, if the charge is sufficiently powerful.

97. The disruptive discharge is always accompanied with a flash of light. This has various shapes, according to the conductors used. Between two good conductors of rounded or blunt surfaces—such as the ball of the discharging rod, and the side of the jar or its nob—we have the *spark*, which is a round ball or globule of light, which passes somewhat zig-zag from one to the other. This corresponds also with the most concentrated and energetic form of the discharge. The distance over which the spark will go, disruptively through the

air, depends upon the force of the charge, and the goodness of the conducting surfaces between which it runs. From a point, or between a good and a bad conductor, the electricity, passing off, produces a *brush* of light spreading out from a centre. The convective discharge through the air yields in the dark a *glow.* When the air is rarefied, the discharge is made easier, and will pass over a greater distance. In an exhausted receiver it will pass through two or three feet in a lambent aurora flame. In the perfect vacuum light is seen, showing that empty space may take on an illumination. "The spark is very bright in condensed atmospheric air, white and intense in carbonic acid gas, red and faint in hydrogen, yellow in steam, and of an apple-green colour in ether and alcohol." By laying on a glass plate stripes of tinfoil or gold leaf, cut across and separated at every inch or short interval, and passing electricity through the whole, there will be a disruptive discharge, and a spark at every break of the continuity, and the entire metallic line on the plate will be illuminated. A great many striking effects of a similar kind can be produced in the dark from the electric light.

98. The concussion given to the air by the shock makes the sound that we hear, which is like the sharp crack of a whip. Both the intermediate air and the surfaces discharged are severely agitated by the sudden return from their electrified to their natural state.

99. There is a very perceptible sulphurous smell accompanying the discharge of electricity. The cause of it has been traced by Professor Schönbein to a peculiar substance formed during the discharge, to which he has given the name of *ozone;* and he has shown that the same substance is produced in other ways, and has certain remarkable properties, such as the power of bleaching cotton, like chlorine.

100. Electrical discharges have an acidifying tendency—that is, they form acids when the requisite ingredients are present. Thus nitric acid is sometimes produced in the air by the agency of atmospheric electricity; and alcoholic liquors are turned sour, or made to pass into the acetous or vinegar fermentation.

101. When the discharge is interrupted by an imperfect or inadequate conductor, it tears, splits, heats, and sometimes sets fire to bodies. Very thin wires are melted; combustible substances, such as phosphorus or gunpowder, are inflamed. The human body feels a violent stunning blow when a charge is sent through it; a very strong charge may cause irrecoverable blindness, or even instant death. A Leyden battery of twelve jars could receive a charge sufficient to kill a man;

and accidental deaths have actually occurred in working with such gigantic batteries.

ATMOSPHERIC ELECTRICITY.

102. Franklin had the glory of discovering the identity of electricity and lightning. By putting up a kite while thunder clouds were floating in the sky, he actually drew down by the string a distinct charge of electricity.

103. It is as yet very imperfectly known by what method the electricity of the sky is generated or excited. It is of the same character as frictional electricity, or that of the common machine; but no friction appears to be used in creating it, nor any other method which we are distinctly aware of as capable of producing electricity of high tension. It is certainly produced by heat as the remote cause, but the precise way in which the heat operates is but partially understood. It was supposed at one time that evaporation evolved electricity, but this is found to be a mistake. Evaporating water yields electricity only when some chemical change goes on at the same time, or when it produces some indirect mechanical action, such as the friction of the water particles in Armstrong's machine. But the relation of the electricity of the air to heat is decisively confirmed by the increase in its amount as we pass into the warm latitudes, where thunder-storms appear with a power and grandeur unknown in cold climates.

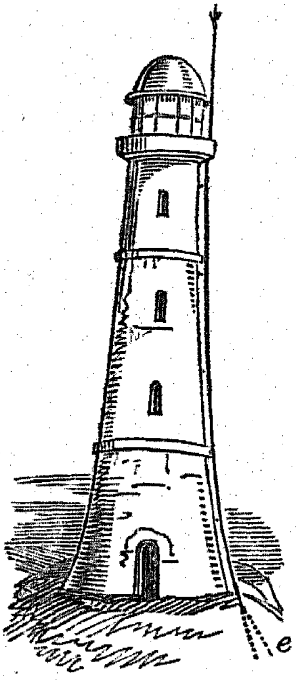
104. The great constant fact respecting atmospheric electricity is, that the earth is always becoming negatively charged, while the air, or all conducting substances contained in it, is at the same time positively charged. In fine weather this goes on without interruption, but it is different for different hours of the day. When the state of the air is steadily observed by an insulated conducting rod, we find that it is least charged at eight in the morning, and most between eight and ten in the evening. In foggy weather the states are reversed, and the air is generally negative. During an actual shower the air is commonly positive, but the raindrops themselves, when examined, are found to be in an opposite state. But during showers, and especially during thunder-storms, the state is constantly changing from one kind to the other. The dense fogs which sometimes settle over a place, and last for hours, have usually a strong negative character; and their being thus highly charged with electricity, seems to prevent them from being dissolved by heat so readily as vapours usually are; for it has been

observed that a cold fog entering a warm room will remain for a considerable time in the visible form.

105. The ordinary action taking place upon the air will therefore render all floating clouds liable to become negatively electric, especially in the lower regions, if we suppose that it is at the surface of the earth that the electricity is generated. If other clouds float above, with a stratum of dry air between, these may become positive by induction, and thus there will be an opposition of states among the clouds themselves, as well as the opposition between the lower strata and the earth. When the accumulation has reached a certain pitch, it will be discharged in some one of the three ways. If there is a communication of moist air between the two charged clouds, or between a cloud and the earth, it will pass off quietly by *conduction;* if there is a great movement among the clouds themselves, it may be neutralised by *convection;* but if two contiguous masses are highly charged, and a dielectric of perfectly dry air lie between, there will be a disruptive discharge in the form of thunder and lightning. When two clouds are mutually discharged in this way, the whole commotion takes place in the upper air; the lightning is faint and diffused; and the thunder always distant. But when a large mass of positive cloud hangs over the negative earth, and when the intervening air is dry, and the accumulation great, the discharge bursts forth between the sky and the ground, and is then the most terrific and dangerous. The light has the zig-zag known by the name of forked lightning; and it is apt to be concentrated in some one spot, which is scathed and scorched by the stroke. The thunderbolts which throw down or set fire to houses, shiver trees, and destroy life, are of this character. All the effects capable of being produced on the small scale by electrical jars and batteries, are caused in the grand scale by these thundery discharges between the clouds and the earth.

106. On the principle that electricity always chooses the best conductor within its reach, Franklin constructed the thunder-rod for protecting buildings. It is a rod of iron or copper from half an inch to an inch in diameter, rising above the highest pinnacle of the building, and extending down along a wall to terminate in the ground. To receive the excitement more easily, it is pointed at the upper end, or divided into several branches, each ending in a point (see fig.) All pieces of metal on the roof should be connected with the conductor, otherwise these might attract the discharge; and they not being continued to the ground, it must pass from them to the imperfectly-conducting stone and wood, and

produce its destructive effects. When a house has a metallic roofing, or whether it has or not, strips of lead should be built into the walls, and connected with one another, and with all the metallic masses of the house, so that wherever lightning strikes, it may find a metallic conductor near to convey it harmless to the ground. The rod ought not to terminate in a dry conducting body, but be conveyed if possible to moist earth (*e*), or to a well, so that the electricity may be at once discharged into a good conducting medium.



107. For the protection of ships, a continuous metallic line is necessary from the mast-heads to the sea. But the conductors in this case must be suited to the changes that have to be made in the masts and rigging during the vicissitudes of a voyage; hence they are made into a chain, or formed of thin flexible strips of copper.

108. If a thunder-storm strike on a house that has no metallic protection, it will choose in preference bell-wires, damp walls, or gilded pictures; a human being will be preferred to dry walls or floors; hence the danger of such a visitation. But the wooden floors are better conductors than woollen cloth or feathers; hence people lying in bed in the middle of a room are likely to escape. The greatest risk is incurred when a good conductor is afforded so far, and then cut short, and an insulating substance succeeds: the lightning is thus attracted and conveyed a certain way with ease, but has then to force its passage by violence, or by going out of its course, to meet in with some tolerable conductor. The human body, from its moist state, stands high in the list of conducting substances, and would be preferred to a great many other things.

109. It is dangerous to stand under trees in thunder-storms. A tree is a slightly better conductor than a human body, and would receive the discharge in preference; but the very fact of its attracting the lightning, while it is not a sufficiently good conductor to carry it quietly to the earth, is a reason for not standing near it. The tree itself may be shivered to pieces, and a portion of the shock besides communicated to other objects. In a forest, where there is a large mass of intervening matter, living beings may pass unharmed.

110. For making observations in atmospheric electricity, a conducting rod is used; but it has to be very carefully insulated, so that it may receive all its excitement from the air,

and neither give to the earth nor receive any from it. In the Electrical Observatory at Kew, kept under the charge of the British Association, the principal conducting rod is a conical tube of thin copper sixteen feet high, and projecting from the cupola of the building. It rests below, within the cupola, on a very strong hollow glass pillar, which is the means of insulating it; and the insulation is very much increased by a lamp, which heats the inside of the glass, in the manner already shown in the electrical machine. There is a certain temperature which renders glass almost a perfect insulator; and although this temperature cannot be given to the whole of the pillar, yet if the lower end is heated higher and the upper end lower, there will be some intermediate portion which will have the exact degree for insulation; and this portion will resist the passage of the electricity as well as if the same degree were maintained through the whole length. A pair of fine platinum wires are soldered to the upper end of the conducting rod; and to increase still farther its attraction for the electricity of the air, a lamp is also suspended at the top, and kept burning. It is found that flame has the power of rapidly receiving or dispersing electricity. The apparatus for lowering and raising the lamp is a silk cord running up the hollow of the rod, and attached to it alone. The lower end of the rod branches out into four brass arms in connection with electrometers, which constantly exhibit the strength of its charge, and show whether it is positive or negative.

111. The aurora borealis has been supposed to be a case of faint lightning discharged far in the upper air, where the rarity is so great that it may flash over great spaces, as we see in an exhausted receiver. But the coincidence between the aurora and distractions of the magnetic needle, render it likely that it is some manifestation of magnetic, rather than thunder and lightning, storms; which is confirmed by the north and south direction of the streamers. This, however, and indeed the whole subject of atmospheric electricity, is as yet very imperfectly understood.

SOURCES OF ELECTRICITY.

112. Hitherto we have regarded friction as the source of electrical excitement; but there are many other ways of evolving it. In general, all disturbances of the molecular state of bodies, whether mechanical or chemical, are liable to produce electricity. All the sources of heat (as well as heat itself), are sources of electricity. We shall now enumerate the various sources in detail :—

1*st, Cleavage* and breakage of bodies is a source of electricity. If a plate of mica is rapidly cleaved in the dark, there is perceived a feeble phosphorescent flame, and we find that the two faces have become charged with opposite electricities. From this it appears that crystals have a permanent polarity in their particles, which is converted into free electricity when they are separated. In the same way, if we break a roll of sulphur, or pound it to pieces, it will be seen to be electric.

113. When two substances have been adhering together by a firm cohesion, if they are suddenly broken asunder they show electricity on the separated faces. If we pour melted sulphur into a wine glass, and, while soft, stick into it a glass tube to be a handle to the mass, and leave it to cool and harden, it will have contracted an adhesion for the glass. If it is now abruptly drawn out, so as to break this adhesion, it will be seen that the two surfaces are electrified.

2*d, Pressure.*—If we take the plates of mica, or other crystal formed by cleavage, and press them together, and suddenly withdraw them, we find they have acquired electricity. But the effects of pressure, as of friction, are greatest with unlike surfaces. Let a disk of wood be covered with silk, and the silk coated with resin, and take a disk of metal, and press the two quickly together without friction; the surfaces, on being separated, will be excited; the metallic disk will be negative, the resined silk will have taken a positive excitement, contrary to the character of resinous bodies under friction. It was observed by Haüy that a crystal of Iceland spar, and a few other minerals, became electric by pressing it with the fingers: but the property is shown to be perfectly general; both good and bad conductors give signs of electricity under pressure. In making the experiments, the substances used are cut into very thin circular slices, and each is laid upon a disk with an insulating handle; they are then pressed together by holding a handle in each hand. A disk of cork, for example, pressed against another of caoutchouc, causes the first to have positive, the latter negative electricity. Crystallised minerals of a transparent character, such as sulphate of lime, are positive when pressed by cork. Slices of fruit, such as an orange, are negative to cork. If one of the substances pressed is a good conductor—a metal, for example—and the other an elastic substance, as a slice of pith, no effect will be produced; the electricity evolved is combined or discharged before the two surfaces can be separated. That this discharge is the cause of the nullity of effect, can be seen by making the separation slowly in the case of cork and orange;

for when the charge of the two surfaces is tested by the torsion electrometer, it is found much feebler than when the operation is quickly performed.

114. The two surfaces must have a difference of character of some kind or other in order to become excited by pressure. If we take a well-dried cork, and cut it across the middle, and press the two pieces together by the insulating apparatus, we may in some instances find an entire absence of excitement. But if one is heated, or receives a higher temperature than the other, a charge will be communicated when they are pressed together; the colder being positive, and the warmer negative. If the one surface be rough, and the other smooth, this difference will suffice to develop electricity, although both should be of the same material and of the same temperature; in this case the smooth surface will be positive, like the cold surface, and the rough surface negative.

3*d*, *Friction*.—This is the source commonly used in the electrical experiments. But in these we confine ourselves to the friction of a very few substances; as the rubbing of sealing-wax and glass rods with cloth, and the action of the glass cylinder of the machine upon a mercurial solution of zinc and tin. In order to investigate and explain the cause of the excitement of electricity by friction, it is necessary to go over a wide range of materials, and determine the precise effects of each pair when rubbed together. It is found that, except where the two faces rubbed are perfectly identical in character, electricity is always evolved by friction. In good conductors, it is necessary to insulate well the pieces rubbed, to keep the excitement from being carried off and lost. With this precaution, all the metals may be made electrical by rubbing them either on one another, or on non-metallic bodies. When disks of different metals are taken, it is found that there is a certain fixed order that determines which becomes positive and which negative. Thus, in the following series, each metal is negative when rubbed on any one following it, and positive when rubbed on any one preceding it:—bismuth, palladium, platinum, lead, tin, nickel, cobalt, copper, gold, silver, iridium, zinc, iron, cadmium, arsenic, antimony. Supposing we were to take a surface of platinum and a surface of iron, the platinum would be negative, and the iron positive; and so on with any other pair we choose to select. To produce the strongest possible indications of excitement, it is necessary to rub quickly with large sweeps, that the parts exciting one another may be separated as soon as possible; the farther the separation, the less the disposition of the two excitements to join again at the place of contact. When the agitation of the surfaces is produced by throwing the powdered particles of a metal on a plate of the same, the effect is like that of pressing or rubbing an unpolished on a polished surface—the powder is positive, and the plate negative.

115. In general, when bodies are rubbed on one another, the one which suffers the greatest agitation of its particles is negative; so that roughness, high temperature, and extent of rubbing, all increase the negative tendency. If two white silk ribbons, taken off the same piece, are rubbed across one another, the one that is moved in its whole length across the breadth of the other will be positive; and the other, which has experienced the most intense action, will be negative. The heat evolved will also be greater in the one rubbed across, and this will add to its negative character. If a white ribbon is rubbed on a black, and if the friction is equal on both, the first will be positive and the second negative, showing that the black dye causes the particles to experience more agitation, or else become hotter than in the white ribbon.

116. The tension of the electricity increases with the pressure and the rapidity of the motion. But there is a limit to the tension which can be produced in any machine; for the tendency of the opposite electricities to come together, and make a discharge at the place of their origin, increases as the tension increases, and at last becomes as great as the power employed to separate them.

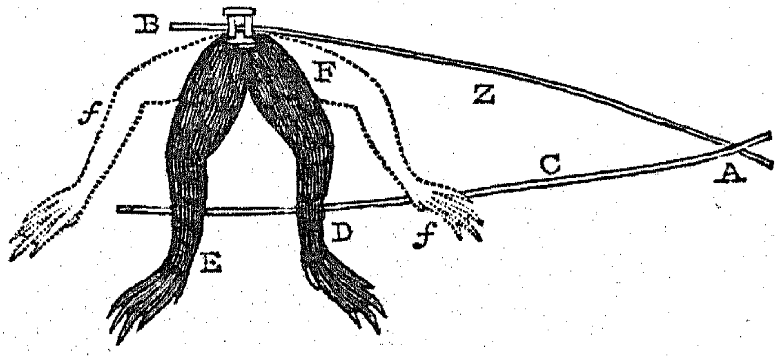
4th, Change of Temperature.—It has been observed that the tourmaline showed electrical excitement while in the act of heating or cooling, whereas it is perfectly free from electricity while remaining at the same temperature. It always possesses two poles opposite in their excitement; by heating, these display a certain polarity, which in cooling is reversed. The development of the electricity seems to result more immediately from the expansion and contraction caused by change of temperature. The topaz, boracite, and several other minerals, have the same property.

117. The production of electricity by heat constitutes a separate branch of the subject; namely, Thermo-Electricity. Chemical actions are also sources of electricity, but the consideration of these belongs more to Current Electricity than to the present head. The sources above given are such as yield the intense and Stationary excitement whose characteristics we have hitherto been engaged in describing.

VOLTAIC ELECTRICITY.

118. Galvanism was the name first given to the electricity produced in constant currents, feeble in intensity, and great in quantity; but it is now agreed that the discoveries of Volta (and not of Galvani) were what really constituted the foundation of this science; it is therefore entitled Voltaism, or Voltaic Electricity.

119. The original experiment of Galvani that excited attention upon this subject, consisted in convulsing the legs of a frog, by making a circle with two metals, and the leg between them. Thus, in the figure, EFD are the legs of a frog, Z is a rod of zinc connected with the nerve which ramifies in the legs, and C a rod of copper touching the rod of zinc at one end and the muscles of the two legs at the other. The circle is thus composed of four parts—zinc, copper, muscle, nerve. When the circle is completed by bringing the two rods into contact at A, after their other ends have been properly connected with the limbs, a convulsion takes place; the sudden contraction of the muscles throws the legs out into the position *ff*. But the very same effect is produced by a discharge of common electricity passed through the nerves and muscles of a limb: hence Volta declared that, in the case of the two rods, a current of electricity was generated; and he inferred from the circumstance that the contact of dissimilar metals was a source of electricity; and, working on this idea, he originated the voltaic pile, which is a series of pairs of plates of dissimilar metals, with a moist substance between each pair. He asserted, further, that the bare contact of the metals is the exciting cause of the electricity: but this has been disputed and denied; and it is maintained in opposition, that a chemical action of some sort is the origin of the electric current. The latter supposition, if it does not explain everything, is at least the most tenable of the two; and we shall therefore commence by enumerating the various chemical actions which lead to the production of currents.



120. If we plunge into nitric acid, one after the other, the ends of the two wires connected with a voltaic electrometer (to be afterwards described), electrical excitement is made apparent. The wire first immersed is seen to have positive electricity, and the other negative. If both were immersed at the same instant, probably no electrical action would arise; but the successive plunging causes the first to be oxidised, while the other is as yet untouched, and the difference of the acid's action on the more and less oxidised wires suffices to give birth to an electric current. This may serve as an example of the circumstances that determine whether a chemical action shall evolve electricity or not; it coincides, moreover, with what has already been stated as to the necessity of some inequality in the kind of materials used in order to bring forth an excitement.

121. When an acid combines with an alkali, the acid acquires positive and the alkali negative electricity. Thus if a platinum capsule, containing a solution of caustic potash, is put in connection with one wire of the electrometer, and if a piece of platinum, connected with the other wire, is moistened with nitric acid, and plunged into the potash, there appears instantly the indication of a current, such as to show that the capsule with the alkali is negative, and the slip ot platinum with the acid positive. Thus one of the most common of chemical actions is a distinct source of electricity.

122. But solution, apart from chemical combination, is a source of electricity. If nitric acid is brought into contact with muriatic (or hydrochloric) acid, there is no chemical combination in the highest sense, there is merely solution (as when alcohol is mixed with water); yet a current arises, and the nitric acid is positive and the other negative. Phosphoric acid is positive to all the other acids, as well as to alkaline solutions. When acids are dissolved in water, they are positive and the water negative; when alkalies are dissolved in water, they are negative and the water positive: so that water is like an alkali to acids, and like an acid to alkalies. The apparatus for developing the current in these cases is the capsule and platina-slip already mentioned: the capsule contains the water, and is connected with one pole of the voltaic electrometer; the acid or alkali, if solid, is held by a platinum pincers connected with the other pole, which is plunged into the water. If the acid and alkali are liquid, a piece of spongy platinum is used, and dipped in the liquid, and then plunged into the water.

123. The case of what is called double decompositions of neutral salts, where two salts decompose one another, and exchange acids and alkalies, making two new salts, is remark-

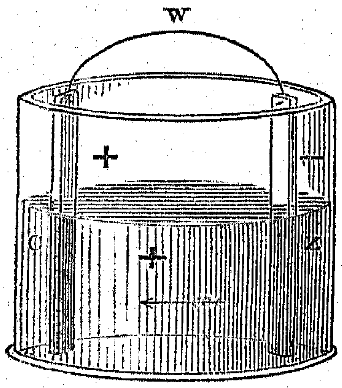
able for giving rise to no current of electricity, provided the quantities are exactly proportional, so as to leave no excess of any element. There can be no doubt that electricity arises in some of the stages of the operation of decomposing and combining, since either of these actions separately always yields excitement; it must therefore happen that the electricities evolved exactly neutralise each other.

124. Since simple solution, as well as chemical unions, gives rise to electricity, it is necessary to discriminate in individual cases which of the two has actually produced a given current. This discrimination can be made, on the ground that a chemical union always evolves heat, and raises the temperature of the mass; whereas dissolutions generally cause cold, and lower the temperature. A delicate thermometer may therefore indicate which of the two actions has happened.

125. In the action of acids and alkalies upon metals, there is apt to be a complication of effects. The simple action of an acid upon a metal is like that of an acid on an alkali; the acid is positive, the metal negative. But when an acid dissolves a metal, there is always the additional effect of the action of the newly-formed substance upon the liquid which the metal is immersed in; this may be of the same character as the action on the metal, and may therefore strengthen the resulting current, or it may be opposite, and weaken it. When there are two metals employed in one circuit, if both are acted on, their effects will contradict each other; and the result will be only the difference of the actions: hence in the voltaic circuit, which commonly consists of two metals and a liquid between them, it is requisite, in order to produce the highest effects, that the one should be acted on and the other not. And in general, the great art in combining several chemical actions to evolve electricity, is to make all the excitements that occur agree with, and not oppose, each other.

126. If two different metals are plunged into the same liquid, the one will probably be more attacked than the other; hence the one most attacked will be negative, and the liquid positive, which will render the other metal positive likewise, in spite of its own tendency to become negative. Now, as the metals differ very much in the quality of being acted on by acids—some, such as zinc, tin, and lead, being very rapidly and powerfully combined, and others, like platinum, gold, and silver, resist chemical action—it is desirable to choose two metals from the opposite extremes. Thus zinc is chosen for the negative metal, and platinum for the positive, in order to yield the greatest amount of action. Copper, although far inferior in resisting power to the precious metals, is yet greatly

superior to zinc, and its cheapness causes it to be much used for the positive element of circuits. Thus, in the figure, let *z* represent a plate of zinc immersed in a liquor capable of acting on it, and *c* a plate of copper; the liquid will combine with the zinc, and give it a negative electricity, and be itself positive; the copper will also be acted on, but more feebly: and hence, instead of being negative, it will receive a positive excitement from the intervening liquid, and act as a conductor to carry round the positive current. When the plates have no connection outside of the liquid, each is attacked according to the degree that it yields to the agency of the liquid; but when the circle is completed by the wire *w* joining the unimmersed ends of the plates, the zinc is more attacked than before, and the copper less attacked. The carrying round of the electric currents causes this effect.

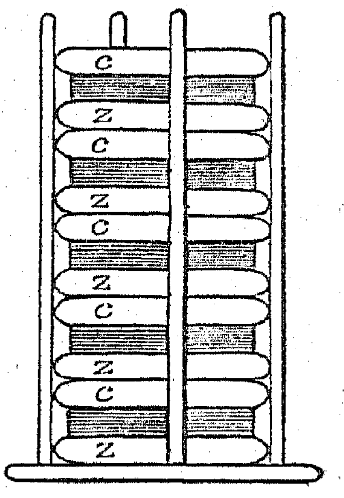


VOLTAIC CIRCLES AND BATTERIES.

127. If a disk of copper and one of zinc are taken, and a wet cloth put between them, electricity will be produced—the zinc will be negative, and the copper positive: if a wire is brought from the zinc to the copper, an electrical *current* will be established; the positive electricity flowing from the zinc through the moist cloth to the copper, and along the wire to the zinc again; and negative electricity flowing in the opposite way, or from the zinc round the wire to the copper, and from the copper through the cloth to the zinc. The apparatus is in principle the same as that figured in the preceding article. Such a combination of zinc, wetted cloth, and copper, makes a couple, or single circle of Volta. The cloth is moistened with water containing a small quantity of acid or salt.

128. The pile of Volta is an aggregation of these simple circles, so ordered that the same currents flow in the same direction in them all. Thus to build up the pile, let an upright stand be formed with glass or wooden rods ending in a bottom: place on the bottom a disk of zinc *z*, then a wet cloth, then a disk of copper *c*; upon the copper lay another series of zinc, cloth, and copper, and so on for any number, the pile terminating in a disk of copper above, as in a disk of zinc below. The zinc end will be negative, and the copper end positive; and if a wire is passed from the zinc to the copper,

the circle is said to be closed. Its action then rises to the highest pitch, and currents of the two electricities circulate around. The lowest zinc, itself negative, renders the moist cloth above it positive, which transmits a positive current to the copper; the copper passes this to the next zinc, which transmits it by conduction, along with what itself generates, to the second cloth; the double force is passed to the second copper, and by it to the third zinc, which the copper touches; the third zinc communicates it to the third cloth, increased by its own action on the moisture of the cloth, and thus a threefold charge is carried to the third copper, and so on. On the other hand, a negative current of equal strength circulates downwards, augmented at each step in the same manner; for the lowest zinc plate, while originating a positive charge proceeding to the copper above it, sends a negative charge the other way; that is, by the conducting wire that goes from it to the uppermost copper, which transmits it through the wet cloth to the uppermost zinc, where another of the same is produced and sent downwards. Thus a double negative charge is passing down through the cloth second from the top to the second zinc, there to be reinforced, and sent to the third, and so on. The surface of contact of a plate of zinc and a film of liquid, is always understood to be producing the two electricities, and sending one off in one direction, and the other in the opposite; just as at the contact of the cylinder and cushion in the electrical machine.



129. By such a pile the various electrical effects can be visibly produced. When the wires attached to the two ends are brought together, a spark may be seen. A shock is felt by passing the current through the body, which is done by holding a wire in each hand. Heat is also produced at the ends of the wires where they touch. But to make the effects decided, a very large pile must be formed, extending perhaps to a hundred pairs or circles, each disk being the size of a crown-piece.

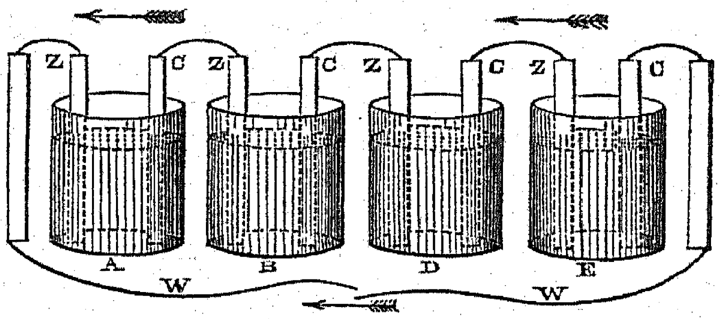
130. The peculiarity of the excitement of the voltaic pile, and of voltaic currents generally, is their feeble intensity. This is the point of contrast between Voltaic and Tension Electricity. When a metallic surface, such as the coating of a Leyden jar, is electrified by the machine, the separation of the two kinds is carried very high, so that their tendency to come together is intense and violent. The standing accu-

mulation at the two ends of a single polarised particle is greater in machine-electricity than in any other kind. If we take a particle of copper in the plate of a voltaic circuit, and a particle of tinfoil in the coating of a Leyden jar, the second is immensely more charged than the first. The distinguishing character of the voltaic electricity is *quantity*. A large amount of excitement of a feeble kind is generated, and passed round the circle. Instead of highly charging the superficial particles of a metallic surface, it charges the entire solid mass with a low intensity, perpetually renewed as it is taken off. If the current is resisted by insulation, the action does not go on heightening the tension of the charge, but stops altogether. When this difference in the mechanical character of the electricities of friction and contact is allowed for, they can be proved to be identical in their nature and effects.

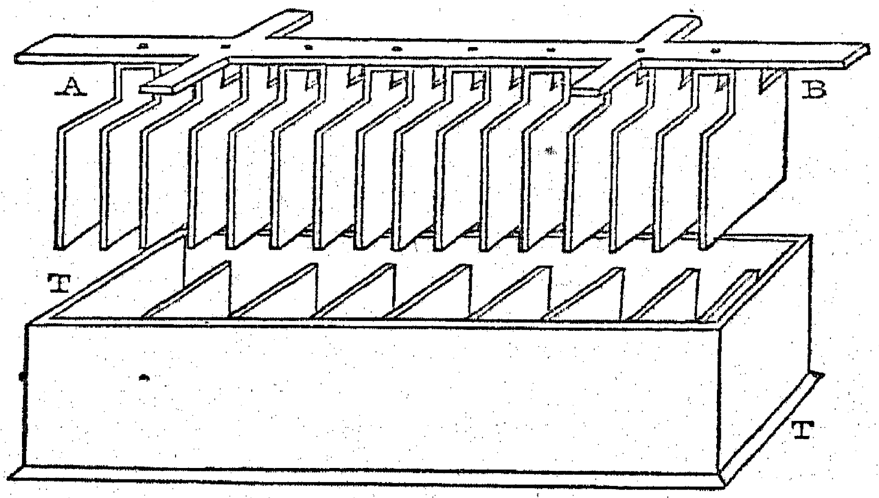
131. The intensity of voltaic electricity is greatest when the pile is made up of a very great number of small plates. Supposing an equal amount of surface of copper and zinc employed, the shock, and other indications of a strong charge, would be greater if it were cut up into many small circles, than if it formed a few large ones. But the actual quantity of the excitement would be greatest with the large plates. We shall afterwards see that chemical and magnetic effects are the measures of quantity independently of intensity. The two qualities may be compared to heat of different temperatures. A tubful of water at 100 degrees has a greater quantity of heat than a cupful at 200 degrees; but the latter is the more intense of the two. The cause of the greater intensity in the long pile of many plates, is the resistance offered by the length of bad conductors through which it passes; but from the intrinsic feebleness of the exciting action, this resistance diminishes the quantity that could be evolved. The presence of the excitement already produced is always a bar to the evolution of new excitement. If the exciting force be of a certain power, it will go on raising the tension till the latter has become so strong as to equal the force; at this point the action must cease, or the opposed electricities will be combined as fast as they are formed, if they are formed at all.

132. As the pieces of cloth between the zinc and copper of Volta's circles are of no use but to contain the acting substance, they may be dispensed with, and the plates inserted in a vessel containing the proper kind of liquid. Volta, accordingly, made an arrangement that he called the "couronne des tasses" (the crown of cups); which consists of a row of cups or jars filled with acidulated water, and each containing a

couple of plates. Thus let A, B, D, E be four jars half-filled with liquid. Into the first is placed a zinc plate Z, and a copper plate C; if these were connected, a current would arise, as was formerly described. But instead of connecting these, let a wire pass from C to Z, a zinc plate in the second jar, which contains also a plate of copper connected with the zinc of the third jar; and in like manner the copper of the third is connected with the zinc of the fourth; the copper of the fourth would connect with the zinc of a fifth; and so on. Let a wire W proceed from the copper at one end, and come into contact with a wire from the zinc at the other; the circle is closed, and the action circulates. From Z to C in the first jar A, there passes through the liquid a positive current, which is carried by the conducting wire to the second Z, and at Z's contact with the liquid joins a second charge, and both pass on to C, exactly as we described in the pile. In the opposite direction a negative current will proceed, reinforced, like the other, at every plate of zinc.

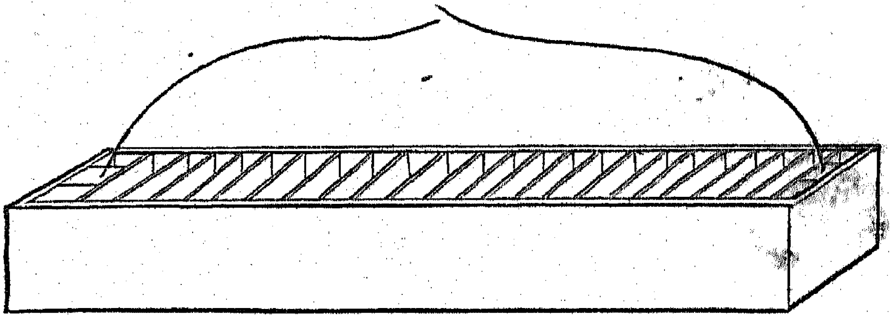


133. A more compact apparatus on the same principle is that called the Trough Battery. A trough of porcelain T T is divided by partitions into separate compartments or cells, each cell being intended to answer the purpose of one of the jars, or contain a pair of plates. The plates are suspended in a piece of wood A B, at the proper distances, and connected with one another by metallic slips. The battery of the Royal Institution, made under the direction of Sir Humphry Davy, and used by him for his celebrated discoveries of the compound



nature of the alkalies and earths, was of this form; it consisted of 2000 double plates, and its acting surface amounted to 128,000 square inches.

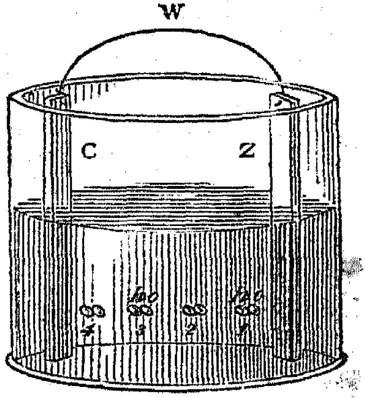
134. Another kind of trough is formed by making the partitions themselves the acting plates. A plate of copper and a plate of zinc are soldered together, and each compound plate makes a partition wall, the liquor being contained between them.



135. Dr Wollaston effected an improvement on the galvanic trough battery by making the copper plates double, so that each enclosed a zinc plate, and faced it on both its sides. The action on the zinc is very much increased by thus enlarging the copper; for it is found that the energy of the circle depends not only on the metal attacked, but on the conducting metal. The greater the conducting surface, and the nearer it is to the zinc, the more intense and rapid is the combination of the liquid with the zinc. In the circles made up of a single plate of zinc and a single plate of copper, the zinc is acted on only on the side facing the copper; but by Wollaston's arrangement, both sides are made to produce currents. The case is exactly analogous to single-surface electricity, where the charge taken in is entirely dependent on the capacity of surrounding surfaces to receive an opposite charge by induction. In so far as zinc is acted on by mere ordinary chemical action, the size and distance of the copper plates are of no moment; but the increase of action arising from the current in a closed circle, is in proportion to the quality and size of the metallic plate that serves as the conductor.

136. All the batteries above described have one especial imperfection among many others; which is, that from the moment they are set in action, their strength constantly decreases. At the end of an hour, or two hours, their power is almost reduced to nothing. This is owing to the reaction on the plates of the products of the chemical combinations. It is therefore a great object to construct *constant batteries* (as well as to arrange the elements so as to prevent the rise of

conflicting currents), and otherwise to heighten and economise the force of the battery. But the nature of the schemes which have been adopted for these ends cannot be understood without attending more closely than we have yet done to what goes on in the voltaic circuit.



137. Let us consider again a single copper and zinc pair immersed in a liquid; and let the liquid in the first place be pure water. Let *z* and *c* be the two plates, and suppose a row of water particles to lie between them. Each water particle is a compound of a particle of oxygen and a particle of hydrogen; and it is almost certain that the following process is gone through when the conducting wire *w* arches the two plates, and closes the circuit. A particle of water (1) is attracted to the zinc by its oxygen constituent; the affinity of the zinc for oxygen surpasses the affinity of hydrogen for oxygen, and the effect of this is to decompose the particle, and form a particle of oxide of zinc, and leave a particle of hydrogen, producing at the same time a certain amount of free electricity; the oxide of zinc having a negative charge and the hydrogen a positive charge. The negative charge of the oxide of zinc passes on through the metal plate *z*, the positively charged hydrogen is attracted to the oxygen of the next particle of water, and its electric state adds to its natural attraction for this atom of oxygen, and accordingly it overpowers the existing attraction that keeps the two elements together, combines with the oxygen, and sets free the hydrogen of No. 2. But this decomposition evolves a new charge of electricity, the water particle being positive and the hydrogen negative. A third particle of water is decomposed in the same way, and a fourth; and so on till the plate of copper is reached. The last particle of freed hydrogen encountering it can decompose no further; it communicates its excitement by contact to *c*, and rises up to the surface, and is dissipated in the air; so that the conduction through the water is effected only through a series of decompositions and combinations, showing the mode whereby liquid particles receive and transmit polarity. The influence evolved at the zinc is necessarily weakened by having to operate so many actions; and it is found that the greater the distance between the two plates, the weaker the current is. Even if nothing were absolutely lost at the transmigration of each water particle, there would be a delay, from time being necessary to all motions, even the quickest; and delay would be resistance.

138. It is found that a circle charged with pure water, such as the above, is very weak, and soon ceases; but if a small quantity of sulphuric acid is added, its energy is renewed and quickened. The oxide of zinc formed on the plate stands between the water and the pure metal, and the action is thereby arrested; but the sulphuric acid combines with and dissolves this oxide, and exposes a clean surface for the further action of the water. But the combination of the sulphuric acid with the oxide of zinc is itself a source of electricity of the same kind as the water action—that is, it makes the zinc negative and the liquid positive; this is, therefore, an addition to the force. But an unfortunate drawback belongs to the acid action. The dissolved sulphate, by being made positive, has an attraction for the copper plate; for this plate, while receiving a positive excitement from the zinc through the liquid, is returning or radiating forth a negative current through the zinc, thus presenting an attraction for all positive elements as well as for the hydrogen. The sulphate of zinc is therefore drawn towards it; and as it cannot go off in air bubbles like the hydrogen particles, it sticks and deposits a coating on the plate, which mars its conducting power; so that what was good in the beginning is in the end an evil.

139. Another source of weakness occurs in the contact of the hydrogen with the copper. The attraction of these two elements is essential to the maintenance of the current; but the same attraction that brings the hydrogen close keeps it there, and constitutes a resistance to the succeeding portions. It would be well that the hydrogen could be got rid of the moment it touches the copper, instead of adhering and stagnating, and occupying the ground which other particles are pressing forward to seize. Now it is found that the addition of nitric acid to the sulphuric acid and water, serves to absorb the free hydrogen, and in this way proves an accession to the strength of the current. But the addition of any new ingredient leads to a new series of actions, both from its chemical agency and from its contact with the other elements of the solution; these new actions being sometimes with and sometimes against the general current. By using sulphate of copper alone, in addition to the water, the hydrogen may be absorbed; the sulphate will be turned into sulphuric acid, and copper, which the hydrogen displaces, deposited on the copper plate, thus maintaining a clean and ever-renewed copper surface. The hydrogen, when not absorbed in such a way as this, is very apt to act upon the compound of zinc dissolved in the liquid, and reduce it upon the copper plate, making a second zinc surface, whereby the action must soon come to

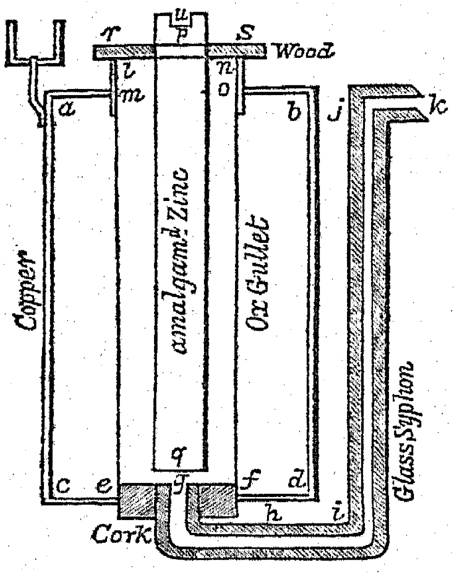
a stand altogether; for two identical plates can yield no excitement.

140. In the forming of constant batteries there are two improvements which have been of especial value. The first is the amalgamation of the zinc, or the coating of it with mercury, thereby presenting a combination of zinc and mercury instead of pure zinc. This is found to diminish to an extraordinary degree the waste of the zinc, or to produce an equal amount of electricity by a much smaller consumption of the acting metal. It is not well understood in what way the mercury contributes to this effect. We have a parallel to it in the rubber of the electrical machine, which is an amalgam of zinc and tin, and far surpasses in effect any other material that could be used; but in neither case is it clearly known what action goes on. The only supposition that has been made as to the way in which the mercury saves the zinc in the voltaic circle, is that it takes away local currents—that is, the naked zinc plate is conceived to produce currents which come round to itself instead of proceeding to the copper, and thus detract from and contradict the general effect.

141. The second great improvement in batteries is the use of *diaphragms*, or porous and permeable partitions between the zinc and copper. These are intended to prevent the dissolved zinc from passing to the copper plate, to be precipitated or reduced there. The partition must, however, allow a free contact of the liquids on each side of it, otherwise it would arrest the action altogether. Many kinds of material have been tried as diaphragms, it being somewhat difficult to find a substance which will allow the liquids on each side to be in contact within its pores, and at the same time keep the one from passing through to mix with the other; besides having other virtues, such as not to become closed up by the precipitation of the salts, not to contain bad conducting material, and not to produce currents from the action on their own ingredients. Bladder, tanned leather, pasteboard, cloth, thin slices of wood, clay, porcelain, &c. have been used, and each has its disadvantages.

142. The *Constant Battery*, introduced by Professor *Daniell*, is constituted as follows:—Each cell or separate circle is of the form of a cylinder, whose construction will be understood by the figure, which is a section down the middle: *a b c d* is the outer cylinder made of copper; it is open at the top, but closed at the bottom, except that there is an aperture *e f*, which receives a cork containing the end *g* of a glass syphon tube *g h i j k*. On the top *a b*, a copper collar *l m o n* rests upon two horizontal arms *a m*, *b o*. Between this collar and the cork

neck at the bottom, a cylindrical diaphragm is stretched, made of ox-gullet, and forming an internal cavity connected at the bottom with the syphon outside. In this cavity there is placed a rod of amalgamated zinc *p q*, suspended from *r s*, a piece of wood lying over the rim of the diaphragm. Into the same inner cavity of the diaphragm is poured acidulated water, which surrounds and acts on the zinc; around the diaphragm, in the outer cavity, there is contained a solution of sulphate of copper. The action of the cell is this: the acidulated water acts on the zinc rod, and excites electricity, at the same time dissolving the zinc, and forming a salt of zinc within the diaphragm; this, from its being heavier than the other liquid, sinks to the bottom, and passes into the syphon, and is carried off if new liquor be added from above to give a sufficient pressure. In this way the product of the action on the zinc is got quit of. The voltaic current is freely allowed to pass through the membrane to the outer cell, and deposit hydrogen on the copper cylinder; which hydrogen, acting on the sulphate of copper, is absorbed by it, and displaces metallic copper, which is deposited on the cylinder, the sulphate being converted into sulphuric acid. A coating of its own substance is thus continually forming upon the copper cylinder, keeping it always fresh and new. To renew the waste of the sulphate of copper, a few solid crystals are suspended in connection with the liquor of the outer cell, which are dissolved as they are required. A battery formed of such cells is found to maintain its strength without diminution for many hours; it also prevents many of the sources of waste of power that were present in former batteries. The power of the battery is found to increase with the temperature; but to work it at a high heat, a porcelain diaphragm must be substituted for the ox-gullet. In subsequent batteries the syphon was disused.



143. A rod of zinc, in a cylinder of copper, is the best form for producing the greatest possible action on the zinc; the latter is confronted all round with a surface of copper, and is therefore acted on equally on every side. A rod and cylinder could be surpassed only by a ball in a hollow sphere, which would not be so convenient.

144. Batteries have been formed by circles where the copper and zinc were rolled up in a spiral, thus affording a large surface in a small solid bulk. It has already been mentioned, that in order to get the electricity in greatest possible quantity, circles of large surface are chosen.

145. *Grove's Battery* is of the same general construction as Daniell's; but instead of copper, platinum is employed, which, being of all metals the least oxidisable, makes the best conducting plate for a circle. Zinc and platinum form the most powerful couple that can be used. Accordingly, Grove makes the outer cylinder of the circle of platinum, and the diaphragm or intermediate cylinder of porcelain, which contains the amalgamated zinc rod. The outer cavity between the platinum and porcelain cylinder is filled with nitric acid, and the inner cavity around the zinc with dilute sulphuric acid. A very powerful current is generated by this arrangement; and although of an expensive construction, from the employment of platinum, it has come into general use. The action is of the same nature as in Daniell's circle. The zinc is oxidised and the oxide dissolved in the sulphuric acid; sulphate of zinc being thrown down, but confined by the partition within the inner circle. The positive current passes from the inner to the outer liquid, and hydrogen is evolved at the platinum, and taken up by the nitric acid. There is no metallic deposit of any kind; but both liquids are changed by their actions, and require to be renewed from time to time.

146. The principles which determine the quantity of electricity evolved in a circle or battery have been reduced to precise mathematical theorems by Professor Ohm. The following are the general statements on which the theorems are founded:—

1*st*, The quantity of the current depends on the tension or strength of the electricity, and on the goodness of the conductors, or the absence of resistance to its passage.

2*d*, The strength and quantity of the current depend, in the first place, on the material used in the circle: the greater the affinity of the acting plate for oxygen, and the less the affinity of the conducting plate for oxygen, the greater the action. In the second place, the result increases with the size of the plates, particularly the conducting plate; it is of no use to increase the zinc surface if the copper or platinum surface remain the same.

3*d*, The resistance in the circle is, first, that of the fluid conductors in the cells; and second, that of the solid conductors, or the wires that close the circuit. The smaller these resistances the more powerful the current.

4th, The resistance of the fluid is in proportion to the thickness of the layer between the plates. By placing the plates very near, the enclosed liquid is so much thinner, and less resisting.

5th, The resistance in passing through the wires is as their length, and as their thinness. The shorter and thicker a wire is the more easily does the current traverse it.

6th, The tension or strength of the electricity increases with the number of the plates. If the plates are few and large, the quantity that could be produced is very great; but if there be much resistance, it is completely checked. Hence if the circuit is closed with bad conductors, or if the wires are long and thin, a battery of many plates is necessary; but if the circuit is closed by good conductors, and the resistance in every way small, a few plates will maintain the current, and produce it in considerable quantity.

147. The conducting powers of the metals themselves are very unequal, supposing them made into wires of equal sizes. The following table expresses the comparative powers of several of them:—

Silver,	136	Platinum,	22
Gold,	103	Iron,	17
Copper,	100	Mercury,	2·6
Zinc,	28		

Thus a copper wire of 100 feet offers the same resistance as a silver wire of 136 feet, or an iron wire of 17, all of equal thickness. Hence in considering the resistance offered by the solid parts of the circuit, the material that it is composed of must be attended to.

148. In like manner, there are great differences in the conducting powers of liquids. Distilled water is very weak compared with saline solutions, alkalies, and acids; but the best of liquid conductors are very feeble compared with the metals.

EFFECTS OF VOLTAIC ELECTRICITY.

149. The voltaic current may produce Heat, Light, Chemical Decomposition, and Mechanical Power, as well as actions on the Animal Frame.

150. The production of *heat* takes place when the current is resisted, but not entirely checked. Thus if the circuit be closed by a bad conductor, and the tension high enough nevertheless to force a current through, the resisting portion is intensely heated. It is a general rule, that when electricity is interrupted, it passes into heat. Thus if a powerful pile is

closed by a thin wire, the latter is very soon turned red-hot and melted away. If gold leaf is made a part of the circuit, it is quickly heated and volatilised. Platinum, which cannot be melted by the heat of ordinary furnaces, yields to the voltaic pile. Iron and steel wire are melted and burned with the emission of brilliant sparks. Thus electricity is one of the means of producing very high degrees of heat. In this action upon bad conductors we have one of the links which associate electricity and heat: a simple mechanical circumstance suffices to convert the one into the other. The relative conductibilities of metals and other bodies can be experimentally determined by observing their rise of temperature when a current is transmitted: that which becomes hottest is set down as the worst conductor when other circumstances are alike.

151. The fusion of all the metals, as well as of many of their mineral compounds, can be effected by passing powerful currents through them when they are attenuated into leaves or fine wire.

152. *Light* can also be produced by the voltaic circuit, sometimes of very great brilliancy. The circumstance of its appearance is the same as in machine electricity; namely, a disruptive discharge through a bad conductor. Of course when bodies are highly heated they become luminous, as a mere consequence of the heat. The metals, when made red-hot, or burned by electricity, have exactly the same luminous appearance as they always have when subjected to the same heating action. The instant that a circuit is closed by bringing the wires together, a spark is seen at the joining; and if, after contact, the ends of the wires are kept at a little distance, a constant stream of sparks passes between them. But the greatest brilliancy of light is caused by making the wires end in pieces of charcoal, and bringing the points of the charcoal together. A dazzling spark is now produced; and if the pile be powerful, a brilliant stream may pass from one point to another, while they are held a little way apart. In the course of the action, the charcoal points are worn away; a stream of particles constantly flows from the one to the other; and the light issues from these particles, as the white light of a gas flame comes from the particles of carbon which are thrown out into the flame, and remain there red-hot for an instant before being burned. When sparks are passed between metallic wires or balls, it is found that the surfaces are scathed, as if their outer particles were torn off and sent in a shower through the blank interval between the two. The disruptive discharge is always productive of mechanical violence and heat, both on the surfaces of the conductors and on

the substance of the intervening dielectric, and this may be the primary cause of the spark.

153. The *chemical action* of the pile in decomposing compound substances is the most important of all its effects, and is such as to render it a great chemical agency. The electric circuit is a medium whereby the power evolved when two bodies combine can be carried to a distance and made to separate a combination, or reduce a compound to its elements. This power was discovered in the beginning of the present century by Carlisle and Nicholson. The first substance decomposed was water, which had been previously shown to be a compound, by producing it from oxygen and hydrogen burned together. The inverse process of reducing the water to its separate gases had not been effected before. If the two wires of a battery are immersed in water at a little distance from one another, bubbles of gas appear at each. The gases may be collected by glass bells (adapted to the collection of gases) being placed over each wire. The wires are formed of platinum, which has no affinity for either gas; if they were of iron, the oxygen would combine with the point of the wire on which it is evolved, and form an oxide. The quantity evolved will increase as the wires are brought nearer; and it is increased still further by substituting metallic leaves or thin strips for the wires. Oxygen always rises at the positive wire, or the wire from the zinc; and hydrogen at the negative, or the wire coming from the copper or platinum end of the battery. The bulk of the hydrogen produced is twice that of the oxygen, which is in accordance with the proportions which combine together to produce water.

154. The action which takes place in the water by a current of electricity passing through it, is a series of decompositions and combinations exactly like that described as occurring between the copper and zinc in the cell. The positive wire attracts a particle of water by its negative atom, the oxygen, and with a force that overpowers its attraction for the hydrogen atom, which is set free with a high negative charge; by this charge the hydrogen acts on the next oxygen atom, and draws it away from its hydrogen, making a new particle of water. The hydrogen, now set free, goes to a third water particle, and decomposes it; and so on till the other wire is reached, which, being highly positive, the hydrogen ultimately comes upon it, and is carried off, so that although decomposition passes all through, the gases are set free only at the wires. Here, then, we have the electricity given forth by the combination of zinc with oxygen in the cell, passed along and expended in overcoming the affinity of the two

elements of water for each other. In this case we may say that electricity and chemical affinity are one and the same thing; the electricity is, in fact, nothing else than chemical affinity set free and conducted round a circle in a current, to act as such in another place. The remarkable thing is, that the chemical polarity is transmissible through metallic conductors, as well as through compound substances, where it acts strictly in its own character.

155. When Sir Humphry Davy had constructed the Royal Institution's large battery of 2000 plates, he applied it to the decomposition of bodies, and discovered that the alkalies, such as potash and soda, resolved themselves into oxygen and a metal. The earths (lime, for example) were similarly decomposed. The discoveries of Davy have been extensively followed up, and the conditions of electrical decomposition accurately ascertained. It is not all compounds that can be decomposed by the voltaic battery.

156. The term *electrolysis* is applied to decomposition by electricity; *analysis* being the term used by chemists for ordinary decomposition. Bodies which can be decomposed by the current are called *Electrolytes.*

1*st*, The first principle of electrolysis is, that the compound must be in a *liquid* state. Solids are not decomposable. Ice, for example, resists the most powerful currents. Hence if a solid body is insoluble, it must be melted, and in that state held between the poles of the battery.

2*d*, The second principle is, that the elements always take a definite direction. The oxygen goes uniformly to the positive pole, and hydrogen or a metal to the negative. Upon this tendency substances are classed and set down as positive or negative in character, according to the pole to which they go. Thus oxygen being attracted to the positive pole, is reckoned an electro-negative substance; hydrogen and metals electro-positive. When a salt is decomposed, the acid goes to the positive pole, the base to the negative. If sulphate of copper, for example, were taken, sulphuric acid would appear at the positive pole, proving itself to be electro-negative like oxygen.

3*d*, In the third place, the chemical actions are equal to one another; the combination which originates the electricity is exactly equal to the decomposition that it can cause. A certain amount of zinc, oxidised and dissolved, will yield an equivalent amount of decomposing force; or should, if the conduction were perfect, decompose exactly the same quantity of oxide of zinc. When substances are combined together in chemical union, there is generally an evolution of heat or electricity, as if less of these was required in the compound than is contained in the substances in their separate state. Accordingly, when a compound is decomposed, whatever was given out at the time of its formation is taken back again; so that while combinations give forth certain influences, decomposition absorbs these. And in the voltaic circuit, it is found that the decomposition between the wires is exactly measured by the amount of material consumed in the cells, according to the scale of atomic proportions. It is precisely analogous to the case of what is termed *the double decomposition of salts.*

4*th*, None but simple compounds can be decomposed. Complex compounds, such as sulphuric acid, nitric acid, peroxides, and perchlorides, are not decomposable by the current. Protoxides and protochlorides, or the combinations of metals with the lowest proportion of oxygen and chlorine, represent the decomposable substances. Chlorine, like oxygen, is an electro-negative element: when it has been combined with hydrogen (hydrochloric acid), or with a metal, it is evolved at the positive wire of the circuit. The elements of hydrochloric acid are sometimes used to designate the two constituents of an electrolyte: the atoms that pass to the positive pole are called the *chlorous* molecules; the others, which pass to the negative pole, are called the *hydrous* molecules.

5*th*, The affinities of the most opposite substances are the most liable to be overcome by the electrical current. Thus oxygen and the metals are reckoned intensely opposite in their character, and by virtue of this opposition, their chemical affinity (which is regulated on the principles of polarity, where opposites attract) is intense; and the action of electricity in counteracting this affinity is also decided. Chloride of sulphur, which is a compound of elements not much opposed to each other, is not decomposed by electricity.

157. The *shock* of the voltaic pile differs from the discharge of a Leyden jar; the electricity of the pile being of feeble intensity, it does not give the blow received from the jar. The greatest shock is derived from the pile of many plates. If, after moistening the hands in salt water, to heighten the conducting power of the skin, we grasp the two wires, one in each hand, a shock is felt at the first contact, and then a heating current up the arms, and a tingling sensation in the hands. A shock is also felt at the separation, arising from the sudden return of the polarised fibres of the arms to their natural state. If the tongue is placed between two wires, or between a piece of zinc and a piece of silver which touch one another, a bitter taste is felt. When a current passes in any way through the eyes, a flash of light is seen. When strong

voltaic batteries are discharged through the bodies of animals recently dead, their limbs and features are convulsed and made alive in a hideous way. Experiments have been made on executed criminals, which showed that electricity could in some degree act the part of the nervous currents in moving the bodily organs. By stimulating the nerves of the lungs, a laborious breathing was recommenced; by passing currents through the nerves of the face, the features moved and stretched themselves out into horrible grimaces; when one wire was connected with the hip and another with the heel, the leg, if bent, threw itself out with great force. In the same way the fist could be closed or the hand opened by touching the proper nerves with one wire and the points of the fingers with the other. These results are only extensions of the original experiments of Galvani.

APPLICATIONS OF THE VOLTAIC CURRENT.

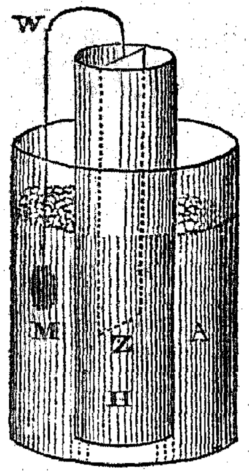
158. The first practical application of voltaic electricity to the arts, was the protection of the copper bottoms of ships from the destructive action of the sea water. Sir Humphry Davy suggested that nails or wires of zinc should be fastened at intervals on the copper plates, which would cause a circuit to be formed of copper, zinc, and salt water. In this case the copper would cease to be acted on by the water, and would serve as a conducting plate to the zinc, which would be the substance wasted. Thus a small expenditure of zinc would come in place of a great expenditure of copper. A piece of zinc, equal to the head of a small nail, was found sufficient to protect between forty and fifty square inches of copper. The value of the application was, however, neutralised by a consequence which had not been foreseen. The protected copper bottom rapidly acquired a coating of sea-weeds and shell-fish, whose friction on the water became a serious resistance to the motion of the vessel, and it was discovered that the bitter poisonous taste of the copper surface, when oxidised, acted in preventing the adhesion of living objects. The principle, however, has been applied with success to protect the iron pans used in evaporating sea water.

159. The greatest application of the voltaic circuit is the *Electrotype;* or the process of multiplying impressions of medals, coins, engraved plates, busts, &c. which was developed about the same time by M. Jacobi of St Petersburg and Mr Spencer of Liverpool. It is founded on what takes place in the circle of Daniell, where a solution of sulphate of copper is in contact with the copper plate, and deposits on it metallic

copper. If the original plate were of a certain form, the deposited plate would exactly fit it; and if the latter could be taken off whole, its surface would be exactly the reverse of the former. If the one were a coin in relief, the other would be a coin with a hollow impression. As the copper is deposited in a shower of the finest particles, it must completely enter all the depressions and lines of the plate, and form a surface so faithfully exact in its correspondence, that no human perception could discern a difference. The requisites of the process are, that the thing to be copied shall have a metallic surface, so that it may become the conducting plate of a circle—that something be done to prevent the coating from adhering too strongly to the original—and that the deposition should be so conducted that the deposited plate may have a close metallic texture.

160. The first discoverers confined themselves to the copying of metallic surfaces, such as copper plates and coins; but a method has been found of copying plaster of Paris, wax, wood, or any non-conducting substance, by covering the surface with black lead—a form of charcoal, which answers the purpose of a conducting plate.

161. The apparatus for copying a medal or coin consists of a cylindrical vessel, containing in it another cylinder of porous porcelain to serve as a diaphragm. Thus A is the outer cylinder; H is the diaphragm, which contains the zinc plate Z immersed in acidulated water. The outer space is filled with sulphate of copper, and in it hangs the original medal M, connected by an arching wire W with the zinc, and making a voltaic circle. The medal is covered over with wax or grease behind, and on the edges, or wherever the copper is not to be deposited. To prevent inseparable adhesion, the face is covered with a slight varnish. The action of the circle then precipitates copper on the naked surface of the medal, and goes on adding to it as long as may be desired. If the action is slow, the coating is so much the harder. To make a good impression of tolerable thickness, one or two days are allowed. If the hollow impression thus derived is put into the circle, and itself coated, a surface will be produced in relief, which will be a perfect fac-simile of the original coin. To save the double process of making first a hollow and then a relief, a cast of the original may be taken in wax or plaster of Paris, or other fusible material; this cast will then receive a surface of black lead, or of fine copper bronze, which can be laid on with a



brush. It is now a conductor, and may be inserted in the circle to receive a deposit, which will exactly resemble the original object.

162. To make gold or silver medals, solutions of salts of these metals must be substituted for the sulphate of copper. The surface deposited on requires also to be previously coated with gold or silver. The difficulty of the process is much greater with the precious metals. It requires a more powerful current to precipitate them. For silver, the solution may be nitrate, sulphate, or acetate; for gold, a very strong nitro-muriatic solution (chloride of gold) is requisite.

163. For copying engraved copper plates a larger apparatus is used: the circuit is completed with copper and zinc, like a Daniell's circle, and the deposition is made in a vessel apart, in the manner that decompositions are effected. Thus the vessel D D contains a cylinder of copper, whose place is marked by the waved lines E E; within this there is a porous cylinder O O O for a diaphragm, and within it a zinc cylinder Z Z, nearly filling the porous cylinder, but not touching it. The usual charge of liquids is applied without and within the porous partition. On the copper cylinder there rests a perforated cover S S for holding crystals of sulphate of copper, to keep the solution beneath in a state of saturation. Thus are supplied all the parts of a single circle. In a vessel apart, AB, lies the plate to be coated *b*, connected by a wire with the zinc cylinder of the circle. Another plate *c*, of oxidisable metal, faces it at a little distance, and both are immersed in the solution which is to furnish the metallic precipitate. The connecting wires proceeding from the plates in the circle are fastened tight to the wires from *b* and *c*, by screws X and Y, to make the conduction as good as possible. When the circle is closed, electricity is generated in the cylinder, and passed to the plates in the depositing vessel. The liquid between these plates is decomposed, oxygen is evolved at *c* the negative pole, and metal on *b* the positive pole. The plate *b* being prepared in the manner above described in reference to medals, by coating the back and edges with wax, to limit the deposition, and by varnishing the face to prevent adhesion, a reverse copy of its surface is procured. If the original engraved

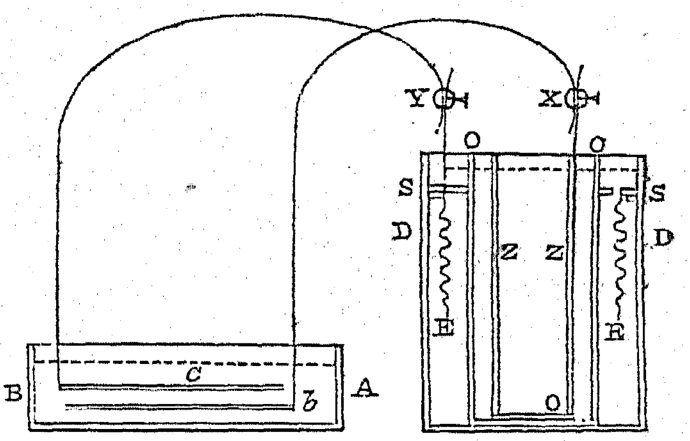


plate is employed, the plate formed from it when put into the apparatus, will be covered with a second plate identical with the original; or if a cast is first taken, an identical copy may be procured by one deposition. It is possible, by regulating the circle, to obtain a deposited plate superior to the engraved plate in the quality of the impressions which it gives when printed from.

164. The improvement thus effected in the art of engraving is very great. When a copper plate is engraved, and impressions printed off from it, only the first few, called "proof impressions," possess the fineness of the engraver's delineation. The plate rapidly wears and becomes deteriorated. But by the voltaic process, the original plate can at once be multiplied into a great many plates as good as itself, and an unlimited number of the finest impressions procured.

165. Another form of applying voltaic electricity to the plastic arts, is the *voltaic etching*. The ordinary process of etching consists in covering a copper plate with a coating of wax, and by a graving-tool cutting out the sketch in the wax down to the bare copper. The portions intended to be in relief are left covered, and those to be hollowed out are laid bare. The plate is then immersed in acid, which eats away the exposed surface to some depth, but is prevented from acting on what is covered with wax. The wax is then dissolved away, and there remains a sketch in relief of the engraver's design. But by the new process, the plate, after being waxed and sketched, is immersed in the depositing vessel of the circuit, and is coated with copper wherever the wax has been cut away; and in this manner a relief surface is given corresponding to the figure that was formed in the wax. This is the opposite of the acid action, which makes the hollows where the plate is laid bare; and therefore, in engraving the surface, an opposite course has to be pursued. The wax must be cut where relief is wanted, and left where the hollows ought to be.

166. A still further extension of the art of voltaic engraving has been proposed by Kobell of Munich, by which pictures drawn in Indian ink may be multiplied. A copper plate, silvered over, is used for drawing on. The colour is spread over the silver surface in such a way that the brightest lights are naked silver, and the paint is laid on according to the depth of the shadow, the strongest shadows having the thickest coating. The plate is then covered over with a wash of finely-pulverised black-lead, and put into the depositing cell, and a copper plate formed upon it. This plate will be in relief where the lights of the painting are, and hollowed in propor-

tion to the depths of the shadows. If it is now printed from in the manner of an engraved copper plate, it will yield impressions similar to an Indian ink drawing.

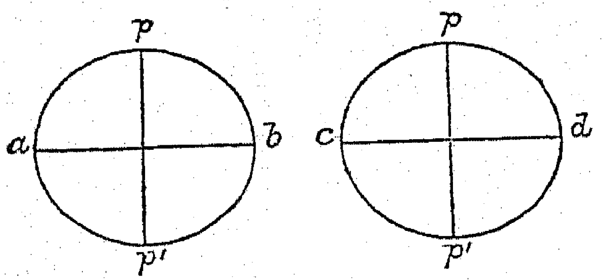
167. *Gilding* and *plating* are now performed very successfully by voltaic deposition. Any metallic surface can be gilded, or silver-plated, to whatever thickness may be desired. A platinum surface can also be communicated. In this way the precious metals can have their usefulness very much extended. Plants may, in like manner, be coated over with copper, and have their forms preserved for any length of time. So baskets and wickerwork can have a metallic surface communicated to them.

ELECTRO-MAGNETISM.

168. It had long been observed that electricity was capable of producing magnetic effects. The needles of ships' compasses, when struck with lightning, always underwent a change in their magnetic character: on some occasions their poles have been reversed, what was the north before becoming the south. Disturbances of needles have also been caused by shocks from Leyden batteries. It was thus generally supposed that an intimate connection of some kind subsisted between electricity and magnetism. The discovery of the real nature of this connection was made in 1820 by Professor Oersted of Copenhagen.

169. If a magnetic needle is held along the conducting wire of a voltaic circle in action, it is made to deviate: if it is suspended along and *above* the wire, it instantly turns about and hangs directly across it: if it is next hung along and *beneath* the wire, it will deviate and lie across, but the ends will be the reverse of the former case—the end that went to one side of the wire is now on the other side: if the needle is hung along the wire *at one side*, or in the same horizontal plane, it dips; one end falling beneath the level of the conducting wire, the other rising above it: if carried to the *other side* of the wire (without being reversed), it dips in the same way, but the pole that was down is now up. Thus it appears that a voltaic current has the power of acting on a needle; but that this power lies not in the direction of the wire, but *across it*. It is as if a magnetic power encompassed or circulated round the channel where electricity flows; or as if a particle, in receiving and transmitting the electrical

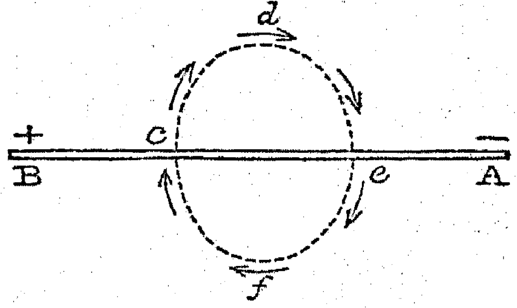
polarity, acquired also a pair of magnetic poles and a magnetic axis, lying directly across the electric axis. Thus let there be two adjoining particles of conducting wire, and suppose that the passage of the electricity lies through them, and that, in transmitting it, *a* is positive, *b* negative, and *c* positive, and *d* negative; then drawing a cross axis *pp′*, the points *p* and *p′* are magnetic poles; or rather if a cross circle were described, the whole circumference would be magnetic; a current of magnetic attraction would go round it, so long as a current of electrical polarities went along from one to the other. Thus while the line of chemical attraction lies one way, the line of magnetic attraction is transverse to it. In chemical decompositions, the separated elements pass in the direction of the current, the attractions and repulsions which it produces on them are in its own course; but the attractions and repulsions that it exerts on magnetic bars is across or around its course. Under this singular and unexpected condition an electric current is a magnetic force. The voltaic circuit is a revolving magnet.



170. We have stated that if a needle be hung along the side of a voltaic wire, and level with it, one end will be depressed and the other elevated. If the needle has its ends reversed, while it is kept on the same side of the wire, the same pole will be down, although pointing along the wire in the opposite direction. But if the voltaic current is reversed meanwhile, by fastening to the copper the end of the wire that came from the zinc, the dip of the needle is reversed, the raised pole is now depressed. So that the new magnetic force has a genuine polar character: a south pole circulates round the wire one way, and a north pole the opposite way, with the same current; but the reversing of the current makes a reversal of the magnetic circulation.

171. The connection between positive and negative currents, and north and south poles, is somewhat puzzling to remember. It must, in the first place, be borne in mind, that the north pole of a needle is that which points to the north pole of the earth: this designation, although erroneous, and against the laws of magnetic attraction, still continues to be used. Let AB be a portion of a conducting wire, A being the *negative* or zinc end, and B the *positive* or copper end. Then a current of positive electricity is flowing from A to B, or from right to left, and a current of negative electricity from left to right.

If now the needle is held along and above the wire, its north pole will go away from the observer in the direction of the arrow at *d:* if it is held below the wire, in taking its cross position the north pole will point to the observer in the direction of the arrow *f*. When held along the wire on the same level, and between it and the observer, the north pole is elevated, as is pointed out at *c;* on the other side of the wire, the north pole is depressed, as shown by the direction of the arrows at *e*. Thus while a positive current of electricity flows from right to left, the north pole of a needle is carried round in the direction that we would turn a handle with the right hand; and consequently a current of *south* magnetism flows in that direction. Or we may say that if a positive current passes before the breast from right to left, the head would represent the north pole of the attracted needle, and the feet the south pole.

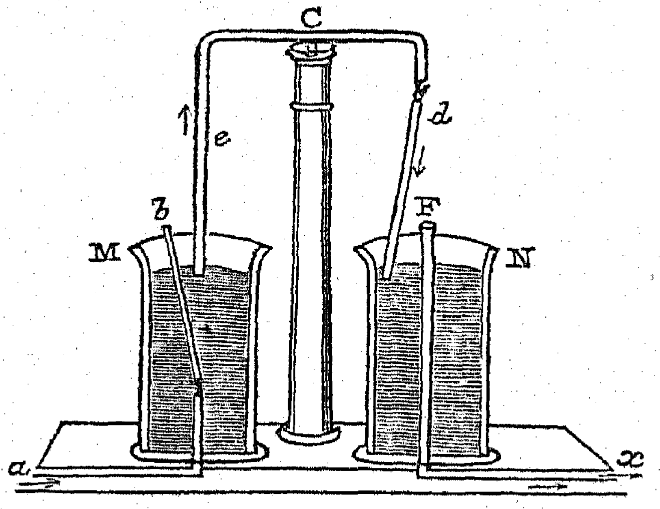


172. If the wire of an electric circuit is thus a magnet, it ought to show attractions and repulsions for other electric wires. This actually takes place. If the wires of two circuits are laid alongside of each other, and are free to move, they are mutually repelled if the direction of the current is the same in both, and attracted if the currents are contrary; so that without the mediation of a steel magnet, the forces circulating round the wires are able to show themselves.

173. Nothing but a *current* of electricity can produce magnetic power: the charge of a Leyden battery, however intense, has no effect. But during the discharge, which makes a current to flow, the magnetism may become apparent. For magnetic purposes the *intensity* of a current avails nothing, intensity being connected with stagnation or resistance; the effect depends solely on the *quantity*. Hence batteries made up of very large circles are used in electro-magnetism. Chemical and magnetic power are both in proportion to the quantity of the excitement, without regard to its tension, or that virtue whereby it could strike a blow or force its way through resistance.

174. An apparatus has been contrived to exhibit in action the revolving power of the magnetism of the electric current. It may be so arranged that a magnet shall revolve round a wire; or, on the other hand, that a wire shall revolve about a magnet. The figure represents the method of producing both effects. M is a glass cup containing mercury, through whose

bottom rises a wire from *a* the conductor of a circle. To the bottom of the cup is attached by a thread a magnetic rod *b*, which floats in the mercury, and is long enough to rise above the surface. Another wire, C *e d*, coming through the pillar C from the other end of the circle, dips into the mercury, and a metallic communication is thus formed between it and the wire entering at the bottom of the cup. A current of electricity now passes along the wires and through the mercury. The upper end of the magnet *b* is within the range of the force circulating around *d*, and, being free to move, it actually revolves about the wire so long as the current continues. By the arrangement in the other half of the figure, the wire revolves round the magnet. N is a glass cup of mercury, and F a magnet fixed to the bottom, and projecting above the surface. The wire from *x* enters the bottom of the cup and touches the mercury. The wire *d* is hung from a hook, and its end dips into the mercury, which forms a metallic or conducting connection between it and the bottom wire. The circuit being closed, the magnetic action commences; the current of force circulating around the wire encounters F the pole of the magnet; there is a mutual action, but F, being fixed, the movement takes place on the wire, which describes a circle in the mercury around F. Both actions may go on from one current, circulating along *a b e* C *d x*, and the revolutions will be in the same direction; for although the current that passes up one wire passes down the other, and reverses the magnetic circulation, this is exactly met by the magnet moving in one case and the wire in the other. If the same current passed up both wires, the revolutions in this arrangement would be opposite.



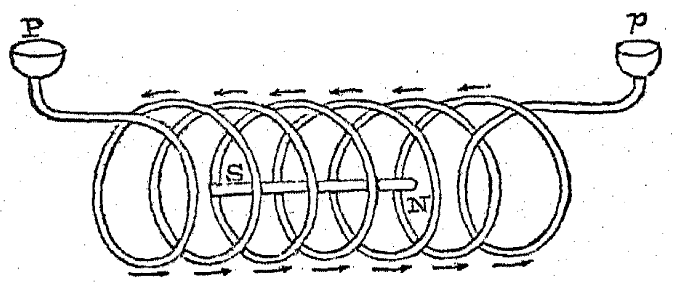
175. A magnet has been made to revolve about itself by passing an electrical current through it, to the middle, and no farther. If the current were passed from end to end, it would urge the one end to revolve one way and the other in an opposite way, and no effect would arise; but by confining it to one-half, the rotation is produced. This may be done by immersing it up to the middle in mercury, and passing electricity into it at the upper end. The current on descending

the bar to the surface of the mercury passes off there without entering the immersed half.

176. The electro-magnetic force acts upon soft unmagnetised iron on the same principle as the ordinary magnet. Indeed its power is best developed by being inductively communicated to soft iron bars, which are magnets so long as they are under its influence. An iron bar, made magnetic in this way by an electric current, becomes an electro-magnet, and by it we can produce every effect of the common magnet.

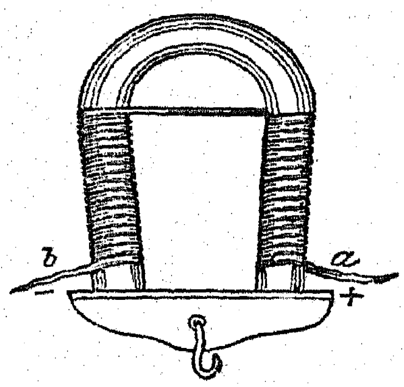
177. A needle of soft iron, laid across a conducting wire, lies in the wire's magnetic direction, and is magnetised by induction. But the action of a single straight wire upon an iron rod would be very feeble. If, however, we bend the wire round the rod, and coil it again and again, we increase the amount of the magnetic circles which act on the iron. Instead of an inch of wire communicating its influence, we may have the inductive force of many feet, and a very powerful magnetism will be imparted. It is by coiled wires, therefore, that electro-magnets are formed. A spiral coil is technically called a *helix*. Such a form possesses all the powers and properties of a magnetic bar when the electric current passes through it. It attracts and repels other magnets, communicates temporary magnetism to soft iron by induction, and permanently magnetises steel.

178. A striking effect of the attraction of a magnetic bar by a helix is shown in the figure, which represents a coil ending in two little cups P and *p*, where the communications are made with the poles of the battery; a small portion of mercury is poured into each cup, and the battery wires are dipped in the mercury, which thus forms a very perfect metallic junction. If a magnet S N is laid in the coil, and the circle completed, the action is such that the magnet starts up and suspends itself in air in the centre of the hollow, and hangs there so long as the electricity circulates. The opposing actions of the different ends and sides of the wire so neutralise each other, that it is not drawn either out or in, or nearer to one side than to another; and its only position of rest is a nearly central station: its own weight necessarily adds to the downward tendency, and keeps it a little below the axis of the spiral.



179. In communicating temporary magnetism to a soft iron bar, with the view of forming the electro-magnet, we

may choose either a straight bar or a horse-shoe: the latter is represented in the figure:—The wire *a* from one pole of the circuit, is coiled round and round the iron many times, and goes off at *b* to join the other pole. If the positive current pass in at *a*, *a* will be the north pole of the magnet, and *b* the south, according to the rule already laid down. To make a powerful magnet, the copper wire should be thick, and covered with silk, to prevent the electricity from passing sideways from one coil to another, or to the iron bar. A lifter is attached for the suspension of weights. An electro-magnet may be made of far greater power than an ordinary magnet of the same size. A horse-shoe, whose arms are eighteen inches long, and two inches thick, may be made to sustain 1000 lbs. if a strong current is passed through it.



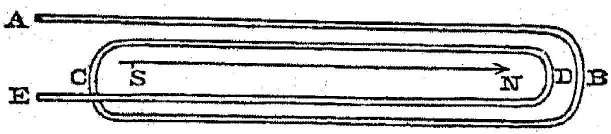
180. To determine which is the north and which the south pole of an electro-magnet, we can revert to the action already described of a straight wire on a needle. If a wire lies before us across our breast, and if a positive current passes from right to left, a needle's north pole is made to describe a right-handed circle—that is, the south pole of the wire's magnetism goes round in the circle in which the right hand would move a winch. If, therefore, a soft rod lies up and down on the other side of the wire from us, its lower end will be south and its upper end north, these being the poles of the wire's revolving action. If the wire is now coiled round it while it stands upright, the effect will continue the same, so long as positive electricity passes from right to left along the coil between our breast and the bar. Suppose we clasp our arms round a tree, and that a positive current circulates from the right hand along the right arm across the breast to the left; in this case the top of the tree would represent the north pole and the root the south.

181. If a steel needle or bar is laid in the inside of a helix, and a strong current passed along, it will acquire a permanent magnetism. The helix which answers best for this purpose is a short thick coil, formed by first winding the wire into one spiral, and then laying upon it a second layer, and then a third, and so on till a great thickness is reached. A powerful current is sent through it, and the bar inserted and moved once forward its whole length, then backward till its middle is in the centre of the coil; the current is then stopped, and the bar taken out perfectly magnetised.

182. Thus the electro-magnetic power is in all respects

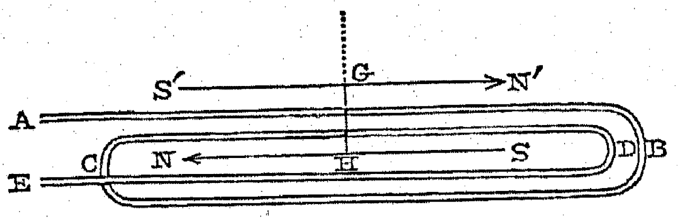
identical with the loadstone and the earth's magnetism; only it can be raised to a much higher degree of intensity than ordinary magnetism. By using a strong battery of Grove's construction, a mechanical force can be developed which is perfectly enormous. There is scarcely any limit to the power which may thus be created. The wire in contact with the iron may, by successive coilings layer above layer, be extended to hundreds of feet; and if the battery is powerful enough to send the current through the entire length, the magnetism is increased in proportion to the quantity of the wire accumulated round it.

183. The electro-magnetic action has been applied to form an electrometer of a very delicate kind, which is essential in experimenting with voltaic currents and electricity of weak tension. It is the proper voltaic electrometer or *galvanometer*. If a magnetic needle S N is suspended within several bendings of conducting wire A B C D E, and hung parallel with the wires, the setting on of the current will make it deviate and lie across; it will thus be a visible mark of the passage of electricity. It will be turned aside by nearly four times the force that would be exerted by a single wire; hence the apparatus has been called a *multiplier*. But instead of two circles of coil, fifty or a hundred may be made, forming a helix with an oval section, and within this the needle is hung. When the instrument is used, it is placed so that the direction of the helix is in the magnetic meridian; hence the needle will, under the earth's attraction alone, lie exactly alongside of the wires. When the current is set on, a deviation will take place; but the needle will not be carried so far as to lie directly across, unless the current be as strong as completely to overcome its polarity to the earth, and its own inertia and the resistance of the suspension. With a weak current, the deviation may be very trifling, but as the current increases in strength, it becomes greater; hence the angle described is a measure of the power of the charge sent through the wire.



184. An improvement has been made upon the instrument, which gets rid of the action of the earth's magnetism, and consequently leaves the needle more free to move aside under the influence of the electrified helix. Instead of one needle hanging within, two needles are used, one within and the other above the oval coil; the upper one having its poles lying reverse to the lower, as in the figure. N S is the inner needle, S′ N′ the outer; being on different sides of the set of wires,

they would deviate in opposite ways if their poles were in the same direction; but the reversal of the poles causes different sides of the current to move them both in one direction. The two may therefore be fixed on one axis of suspension, and they will act under the influence of current as a single needle. But the earth's magnetism will of course affect each of them: since, however, they lie in opposite directions, it will tend to draw N′ one way, and S′, which is on the same end, the other way; and the two attractions will neutralise each other, so that no movement will arise from the operation of the earth's magnetism, if the needles have exactly the same degree of polarity. It is unnecessary with this instrument to attend to a meridian position; and the deviation will be much greater from any given current than with the single needle; consequently the indications will be more delicate. By this instrument very feeble currents can be made apparent.



185. For measuring the force of powerful currents, it is not necessary to coil the wire or to use a silk thread for suspending the needle. A single coil placed in the magnetic meridian, and enclosing a needle on a point, will serve to measure the strength of such currents. The stronger the current, the more will it overpower the tendency of the needle to point to the north, and hence the angle of deviation from the direction of the coil or the magnetic meridian will correspond to the strength of the circulating electricity.

ELECTRO-MAGNETIC MACHINES.

186. Many important practical applications have been made of the voltaic magnetism. Of these the most prominent is the Electrical Telegraph, invented by Professor Wheatstone, and perfected by him and others, and now in extensive operation over the lines of railways.

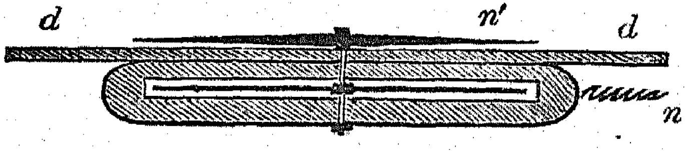
187. The electrical telegraph depends on the power of an electric current to cause the deviation of a magnetic needle, and on the great distance that the power may be conveyed. In the experiments of Mr Wheatstone, it appeared that a current could be transmitted through four hundred miles of wire without being extinguished; so that at the end of that distance it could cause a sensible magnetic action.

188. The apparatus of the telegraph consists, in the first

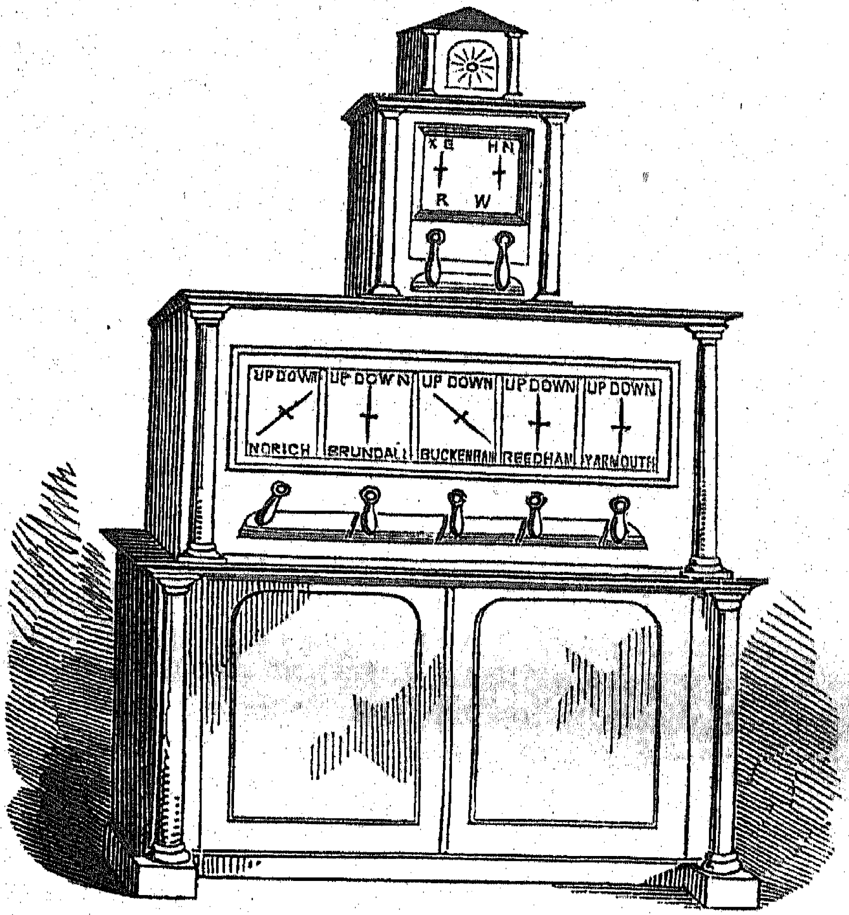
place, of a line of conducting wire suspended on poles, and reaching from station to station. On the first introduction of the telegraph, a pair of parallel wires was thought necessary, in order to complete the voltaic circle; but it is now found that the earth can make the returning part of the circuit, and that it may therefore be formed by means of a single wire. At each end, the wire is carried down to the ground, and attached to a large plate of metal buried there; and the current finds its way through the earth from one of the metallic masses to the other. The wire is formed of iron coated with zinc by a particular process, and receives the name of galvanised iron wire: it rests on the poles in earthenware tubes, in order to insulate the passing electricity.

189. The second essential of the telegraph is the *battery.* The kind of battery which seems to answer best is the partitioned trough, with a pair of copper and zinc plates in each cell. The cells are filled with dry sand, which is moistened with dilute sulphuric acid when it is to be set in action. This arrangement is found to yield a very constant and enduring voltaic current. The greater the distance between the stations, or the longer the circuit, the more powerful of course must the battery be. The resistance to the current necessarily increases with the length of the wire, and at a certain distance it would be too feeble to produce a deviation of the needle, or any other palpable movement.

190. The third necessary part of the telegraph circuit is the *needles.* These are the indicators of the excitement, and the instruments with which the signs are made. In order that the current may deflect a needle forcibly, an oval coil is formed on the principle of the galvanometer; and two needles are used, one within the coil and one without, as in the figure, which gives a side view of the instrument, *n* being the inner needle, and *n′* the outer. As in the galvanometer, the needles are arranged with their opposite poles together, so that the earth's magnetic action upon them is neutralised; and from their being on different sides of the coil, they are both moved in one way by the same current. *n′* is the needle that is visible, and it lies upon a dial-plate *d d*, seen edgeways in the figure. The helix or coil makes part of the great circle; and when the battery is in operation, and the circuit closed, the needle is moved across the coil, or deflects from the upright position which it occupies when unexcited. If several needles are mounted on one circuit, all will be moved in the same way at the same instant.



191. The fourth essential part of the machinery is an apparatus for making and breaking the metallic contact, or closing and opening the circuit, and also for reversing the current, so as to give an opposite deflection of the needle, and thus vary the signal. This has been executed in several ways. The external instrument is a handle that may be swayed to the right or left, according to the deflection to be given to the needle. The accompanying cut represents the Norwich Railway apparatus, with its needles and handles; a separate wire and circuit being necessary for each needle. So few as two needles have, however, been found sufficient to make all the requisite communications. The needle to the left is seen deflected one way, and that in the middle the opposite way. An agreement must be made as to the meanings represented by each deflection or combination of deflections. Thus in a double needle apparatus, each letter of the alphabet and each arbitrary sign must have a different aspect; and yet there are only four simple movements which can be made—namely, a right and left deviation of each needle; the combinations of these movements would give in all twelve distinct configurations of the needles. But by repeating the vibrations, any number of different signals may be made—that is, each needle may be deflected once, twice, or thrice for the same signal; a pause being allowed after the signal is completed, to distinguish between the successive deflections of one sign and the transition to another. At the end of a word a particular sign is made to show that it has been completed. It is found possible to communicate at the rate of fifty letters a minute.



192. The apparatus for signalling may be very various, and many schemes have been proposed with the view of quickening the process of communication. Bain's new system consists of causing the electric circuit to make coloured spots in a piece of paper soaked with sulphuric acid and prussiate of potash; employing the chemical instead of the mechanical action of the voltaic circle to make the indications. The moistened paper is wound in a metallic roller, which is kept moving while the end of a metallic spring rests upon it; the apparatus forming part of the great telegraph circle. While the circle is broken, no effect is produced; but when it is closed, the current passing through the wet paper effects a decomposition that shows itself in a blue spot. At the other end of the line an apparatus of a similar kind is placed; but the strip of paper is dry, and acts as an insulator. It has holes punched in it, which, in the course of the movement, come under the spring, and allow it to touch the naked roller, and make a perfect metallic contact, and thereby close the circle. At the instant, therefore, a hole passes beneath the spring at one end, a coloured spot appears beneath the spring in the apparatus at the other end; so that the series of holes are exactly represented in a series of blue spots. If, therefore, aggregations of holes are chosen to represent letters and signs, these can be faithfully repeated and read; and the apparatus can be driven with far greater rapidity than the needle system.

193. Although the telegraph is by far the greatest application of voltaic electricity and electro-magnetism, it is not the only application. Much ingenuity has been spent in contriving machines for bringing electricity into play as a prime mover, like wind, water, steam, or gunpowder. The mechanical force of an electro-magnet, as we have seen, is very great; and there seems no reason why it should not be used as a source of power in moving machinery. Whether it would be as cheap or cheaper than steam-power, must depend on many considerations. But at all events it might be found preferable to other prime movers in special cases and circumstances. As yet, however, no effective method has been contrived for bringing the power to bear upon machinery. It has the peculiar character of being a very intense force acting through short distances; and it is requisite that this mode of action should be converted into a rotatory motion, in order to be generally applicable to movements. An apparatus has to be formed which will do the same for the magnetic attraction that Watt contrived for the expansive force of steam, when he joined together a cylinder and piston, parallel

motion, cross beam and crank, to convert the reciprocating steam-pressure into a wheel movement. The magnetic force is also a reciprocating force, but of very short range and varying power; and some suitable apparatus must be interposed to transmit its whole amount to the steady whirl of a shaft or axis. The machines hitherto contrived have not been able to communicate the whole power of the magnets to the rotatory apparatus, and they are therefore no fair criterion of the mechanical force which may be obtained from the consumption of zinc and acids in a voltaic circle.

194. Mr Bain has succeeded in applying electricity to move the pendulums and machinery of clocks. For the ball of the pendulum he makes a hollow coil of copper wire, whose opening or axis looks right and left, or in the direction which the pendulum swings. Two magnets are fixed so as to point into the opposite ends of the coil, and face each other. If a current of electricity is sent through the coil, it becomes an electro-magnet, and is attracted to the nearest magnet. Accordingly, means are provided for communicating at every vibration a current to the pendulum, and for cutting it off while it passes the middle line, and recommunicating it at the other end of the sweep. A plate of zinc and a plate of copper are buried, facing each other, in the earth at a depth of at least nine feet, that there may be a constant supply of moisture. The damp earth is thus the exciting element of the circle, which has a permanent action. Wires are carried from the plates, and passed along the pendulum, to connect with the coil which forms its ball. About the middle of the pendulum rod, an arrangement is made whereby the motion of the pendulum closes, breaks, and recloses the current according to the place where it lies in its vibration. The attraction of the magnets is thus made to sustain its motion and the motion of the connected wheelwork. It may be regulated to beat exact seconds like an ordinary pendulum.

MAGNETO-ELECTRICITY.

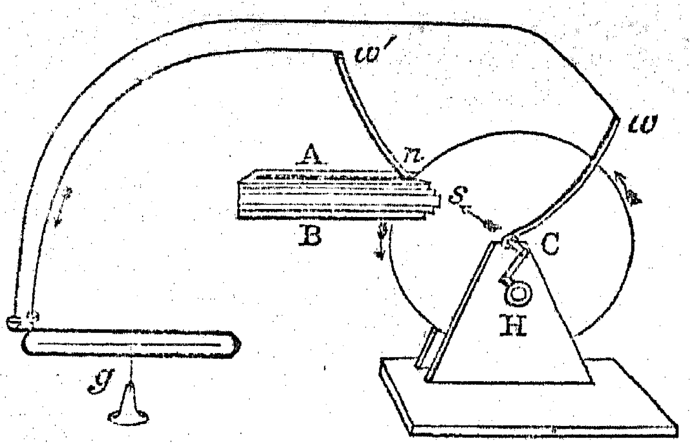
195. Magneto-electricity is the counterpart of electro-magnetism; the one explains the production of magnetism by an electric current; the other shows how an electric current may be produced from a magnet. This branch of the science was created by Professor Faraday.

196. If an electric current and the magnetism of a bar are so closely allied that the first can give rise to the second, it was natural to expect that the second should be able to cause the first; or that a magnet might be so placed with reference to a conducting wire, as to produce in it a current of electricity. The experiment may be tried in many ways. Thus since a helix charged with a current can magnetise a bar lying in it, let us take a bar magnet and put it into a coil which has no connection with a voltaic circuit, but whose ends terminate in a galvanometer, and which forms a complete circle of conducting wire. We have now an active magnet lying in an unactive helix; but no current is observed. Although the active magnet is in the very place where an unactive bar would be magnetised by an active wire, yet the circumstances being reversed, the active magnet cannot induce magnetic currents around the wire, so as to make electric currents run along it. Let us, however, seize hold of the magnet, and instead of its lying at rest in the hollow of the coil, let it be moved backwards or forwards; a current is immediately observed, the needle of the electrometer being sensibly deflected. While we continue to move the magnet in or out, the current is maintained; when we let it rest, the current ceases: so that an active magnet has the power of creating electric currents, if it is moved in the direction of its length across a wire or assemblage of wires. The motion of the bar is essential to the effect. The necessity of motion is owing to the character of the magnetism of a conducting wire; for this magnetism is not a reposing or statical magnetism, but a current or revolving magnetism; and unless the statical magnet is itself set in motion, it cannot be the cause of a current magnetism. The electricity arising from this action is called Magneto-Electricity.

197. If an active wire, in connection with a circuit, lies alongside of another wire that is inactive and connected with a galvanometer, the current of the first has no influence in making a current in the second while both wires are at rest; but at the instant the current is arrested, and the instant

that it is set on upon the first wire, a momentary current appears on the second. While the current continues, there is no action. Let, however, the wires be made to approach each other, and a current ensues on the inactive wire; when the wires are at a stand still it ceases. Or if they are drawn away from each other, a current in like manner arises, but opposite to the current during the approach: so that there are two methods of passing a current from an active to an inactive circle. We may either close or break the active circle, and thereby create an instantaneous current; or we may move the wires nearer or farther from each other, and during either motion we have a current on the inactive circle; the approach making it in one direction, the recession making it in the opposite direction. These effects are designated by the term Volta-Electric-Induction; and the currents Induction Currents.

198. The approximation or separation of the wires is exactly similar to the moving of the magnet in the coil, or across a wire. An active wire is a magnet, and if it is moved sideways towards another wire, the effect is the same as if a magnetic bar were moved endways. The side motion of the one can do exactly what the longitudinal motion of the other can do. In both cases mere proximity has no effect; but, by movement, each can excite a current in a dead circle.



199. Faraday was able to produce a permanent electric current from a horse-shoe magnet by the following apparatus:—A circular plate of copper C is made to revolve upright on a stand, and a handle H is fixed on the axis. Two conducting wires *w* and *w′* are connected at one extremity with the galvanometer *g*, by being plunged in its mercury cups. At their other extremities one of them, *w*, is connected with the axis of the copper plate; the other, *w′*, is made to touch its edge between *n* and *s*, the poles of the magnet A B, placed as represented in the figure. The plate is whirled by means of the handle, and a current of electricity is found to circulate round the wires; the nature of the current is reversed when the motion is reversed. The inductive effect being the same whether a magnet is moved along a conductor or a conductor along a magnet, the action is produced here by the copper edge constantly running across

the direction of the iron. A current thus arises on the edge and passes inward to the axis, and thence along the wire *w* to the electrometer, the opposite current taking the contrary course. When the handle is revolved from right to left, the positive current in the above apparatus has the direction of the arrows. The end of a bar magnet, held near the edge of the revolving copper, has the same effect as the horse-shoe.

200. The identity of electricity and magnetism was still farther confirmed when Faraday discovered that a spark could be drawn from the magnet. At the moment of making or breaking the magnetic contact, or when the lifter either completes the connection or breaks it, a spark is sent forth at the junction; or if the lifter is surrounded with a helix, the spark may be seen in the circle, by having at one part of it two surfaces very near, but not in contact—as a fine point almost touching a surface of mercury. The instant the lifter strikes the ends of the horse-shoe, or the instant it is drawn away, a spark passes through the open interval of the circuit.

201. An induced current, either from a magnet or from an active circle, produces a sensible shock, of the voltaic character, but more severe. Its intensity is higher than the intensity of the original current. When the induction is of the temporary kind which accompanies the opening and closing of the active circle, the shock is instantaneous; but by keeping up a constant induced current by movement, a continuous shock of a very painful kind may be communicated. Machines have been constructed for producing the permanent induction, called Magneto-Electric Machines; and in causing physiological effects, or for acting on the human body, they are the most efficacious of all electrical machines. Their principle is different from the revolving apparatus of Faraday above described. They are contrived so that a lifter may repeatedly make and break its contact with the magnet, and thus induce a succession of currents upon a circle of wire coiled many times round it. The lifter is made as if for an electro-magnet—in other words, it is wrapped round with a great many turns of wire; but the coiling is made so that the ends of the magnet point as it were into the hollow of the coil—that is, the lifter is not simply a cross bar, but has across its ends two cylinders, facing the ends of the horse-shoe, and receiving the wire coils. If the magnet is now rapidly revolved on an axis running between its legs, the constant movement of approach and retreat from the coiled lifter maintains a series of currents, and these are twice reversed at each revolution; for one kind of current arises when one pole approaches one end of the lifter, and an opposite when this pole leaves it and the

other pole approaches. This incessant reversal of the current is probably the cause of the very painful character of such currents when transmitted through the arms. The wires of the coil terminate in small copper cylinders, which are held one in each hand; and if the hands are previously moistened with salt water, the shock will be experienced to the fullest advantage. The more rapidly the magnet is whirled, the more intense will be the action.

202. The machines first constructed made the magnet to revolve as above described; but subsequently they were formed so as to make the coiled lifter revolve, while the magnet remained fixed. The apparatus is so arranged that the shock passes upon the circle through the body only when the keeper faces the ends of the magnet; when the keeper leaves the poles, the connection is broken, and remains broken till half a revolution takes place, when the opposite current is induced as a shock, and instantly stopped. Thus there is given a succession of disjoined and contradictory shocks.

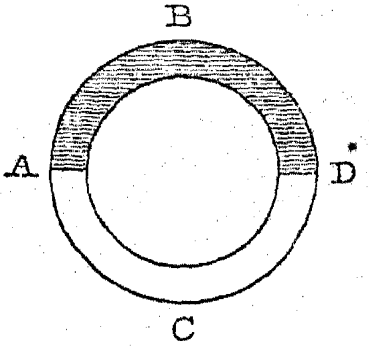
203. Chemical decomposition has been effected by magneto-electricity; but as this demands a copious quantity of the current, it requires large magnets to make it apparent. The machines are generally compound horse-shoe magnets of large dimensions. The wire coiled on the cylindrical branches of the keeper is very long, sometimes many hundred yards. For chemical decomposition an arrangement is adopted, called the *quantity* arrangement, for securing a continuous current in the same direction, as no decomposition arises when the electricity is continually interrupted and reversed; the one polarity must necessarily counteract the other. Hence the machines which give the most violent shocks are sometimes totally inefficacious in decomposing compounds.

204. As the earth is a magnet, it ought to have the same power as other magnets to induce electric currents. Faraday succeeded in proving this to be the case, by making the same arrangements as were necessary for a portable bar. A conducting circle is made to revolve across the direction of the earth's magnetic pole, or at right angles to the dipping needle, and in this way it acquires an electric current, which can be distinctly made evident by the galvanometer. Hence Faraday inferred that voltaic currents must be frequently generated by the accidental movements which take place on the earth. Thus in high north latitudes, where the pole lies almost vertically down, a wheel revolving horizontally would be moving across the magnetic direction, and would have a current induced upon it. So even running water in the polar regions would experience voltaic excitement from the earth's magnetism.

THERMO-ELECTRICITY.

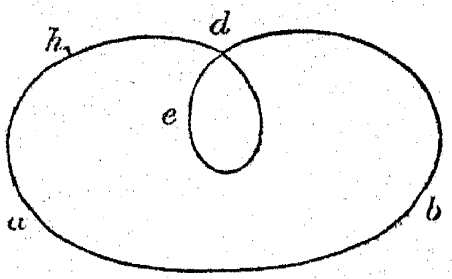
205. It has been seen that an electric current, passing through an inferior conductor, or in anyway interrupted without being completely checked, gives forth heat. Resistance to its passage is the means of converting the polar excitement into an increased temperature of the resisting material. On this condition heat and electricity are reciprocal. But although it has always been very easy to produce heat by an electric current, it was only in 1832 that the means were found of producing an electric current by heat. This discovery, made by Professor Seebeck of Berlin, gave rise to the science of Thermo-Electricity, which completed the evidence of the reciprocity of the electrical and the other effects. Volta had produced the excitement by chemical action, Professor Faraday from the magnet, and now it is derived from heat; its three greatest effects are thus found to be in turn its causes.

206. When two metals whose susceptibility to heat is unequal are soldered together, and heated at the joining, an electric current is evolved. Thus if A B C D be a metallic circle, the one half, A B C, being *bismuth*, the other half *copper*, and if a lamp be applied at A, one of the joinings, it will heat both metals, and cause electric currents to flow round the circle. A positive current will pass from the bismuth to the copper, or round in the direction A B C D, the negative taking the opposite course. Thus when two substances, differently disposed in regard to the reception of heat, are heated together at their point of contact, the discrepancy shows itself in the two metals polarising each other, and yielding electricity.



207. If we heat a wire which makes part of a circle attached to the galvanometer, the heat will be conducted off right and left along the wire, at an equal rate, and no electricity will arise. But if in anyway we cause the heat to pass round more copiously to one side than to the other, a current will be made apparent. Thus if we make a loop upon the wire, and make it touch at the crossing, this will retard the passage of the heat to the side where the loop is, and thereby disengage electricity or polarise the wire. Thus suppose the heat

applied at *h;* it will be conducted along the wire each way; but at the loop *d*, part will go along *d b*, the proper direction, and part will be communicated to *d e*, which will make it return again towards *h*, and, on the whole, impede the conduction on the way to *b*. So that the heat will travel at a greater rate round by *a* than round by *b;* and it would appear that when unequal currents of heat encounter, they issue, not in a simple increase of one another, but in a polar effect, or they make an active voltaic circuit. On the same principle, if one end of the wire is oxidised, it will be made a worse conductor, and electricity will be manifested. A crystallised body may sometimes produce a current on the application of heat, owing to the fact, that the heat passes more easily through one side than through another in some crystals.



208. It is found that when hot water mixes with cold water, electricity is produced; the hot liquor being negative and the cold positive. Other liquids show a similar action; but the kinds of excitement are not invariable: a hot acid mixed with a cold acid makes the first positive and the second negative. Hence it appears that the passage of heat must in general cause electrical polarity; only if two equal portions of heat pass round in a circle and meet, they will neutralise each other's effects, and no excitement will be apparent.

209. If, instead of bismuth and copper, bismuth and antimony are soldered together, the effect will be greater, the disparity of the metals being greater. This last couple is what is usually adopted for a thermo-electric circle, being superior to any other that could be chosen. The following table exhibits the order of the principal metals in regard to thermo-electric combinations:—

Bismuth
Mercury
Nickel
Platinum
Lead
Tin
Copper
Silver
Gold
Zinc
Iron
Antimony.

The farther asunder two metals are in this table, the more powerful is the couple formed by them. Bismuth and iron would make the next best couple to bismuth and antimony. Silver, gold, and zinc are very nearly equal in the effects which they would cause, if coupled with a metal from the other end of the table. Each metal causes a positive current to pass upon any metal beneath it, and a negative upon any metal above it. Thus if platinum and copper were soldered together, a positive current would pass from the platinum to the copper, and the negative from the copper to the platinum; or the actual state of each would be—platinum negative, copper positive; that is to say, if two plates were laid on each other, and heated at the joining, the free side of the platinum would be negative, and the free side of the copper positive. Positive electricity radiates from the joining through the copper mass, negative electricity through the platinum mass.

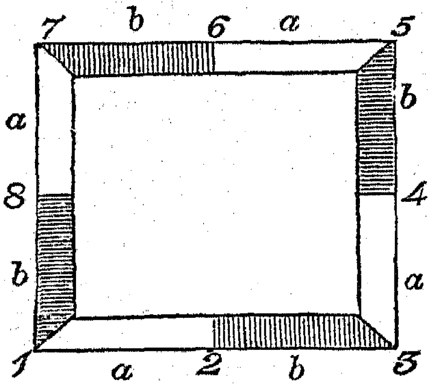
210. Various mineral substances may enter into the thermo-electric circle, such as plumbago, peroxide of manganese, per-sulphuret of iron, and galena. Plumbago is positive to platinum, and stands pretty near the lower end of the table. The per-sulphurets stand near to bismuth.

211. The order of the metals above given does not correspond with their goodness as conductors of heat. Bismuth, indeed, and the metals near it, are the worst conductors of heat; while some of the metals near the other end, such as gold, silver, and copper, are among the best conductors. But there are very decided exceptions. Platinum ranks with gold and silver in conducting power, but it is far removed from them in the thermo-electric series. Iron is inferior as a conductor to all of these, and yet it is nearer the antimony than any of them. It cannot, therefore, be laid down as a rule that the worst conductors of heat rank highest in the thermo-electric series, or that a good and a bad conductor will make an effective couple.

212. But if we classify metals according to their power of radiating heat, or of receiving it by radiation, we find a near coincidence with the above order. A metal does not radiate heat from its surface in the same proportion that it passes it through its substance; the proportion is more nearly an inverse proportion. The worst radiators are at the top of the table, and the best radiators at the bottom. Hence it appears that when heat is applied to the joining of two metals, and when the one is slow at receiving the imparted heat, while the other receives it abundantly, the inequality thence arising is the cause of the electricity. For the heat applied to the couple being that from a lamp or a fire, it is communicated by radiation; and as bodies which radiate well, receive radiant heat equally well, the best radiator will be most heated, and will be negative, and the other positive; so that in general the side of the joining where most heat is received is the negative side, and through it the negative current passes to the wire of the circuit.

213. A single circle, made of a bar of bismuth and one of

antimony, soldered together, makes a simple circuit or couple; but any number of bars may be laid together, so as to make a compound thermo-electric circuit. If they are joined one to the other in a long line, or in a circle, the heat will have to be applied to every second joining. If the first, third, fifth, and seventh joinings are heated, while the second, fourth, sixth, and eighth are cooled, by being laid in ice, the force of the current will be increased. Cold has the same power of exciting electricity as heat, only the current is reversed. The figure represents a compound circuit of four bars of bismuth *b*, alternating with four bars of antimony *a*. Heat would have to be communicated either to the four corners or to the middles of the four sides. If the corners were heated and the middles iced, the effect would be thereby increased.



214. A series of bars of alternate bismuth and antimony may be, as it were, folded together in a bundle, the first, third, fifth, seventh, &c. joinings being at one end, and the second, fourth, &c. at the other end; the bars being kept from touching at their sides by an insulating substance. The last rod of bismuth is connected with a wire, and forms the negative pole; and the wire attached to the last rod of antimony at the other end will be the positive pole. The two ends of the bundle are blackened to increase their absorption. If either face is heated, a current will arise; if one is heated and the other cooled, the current will be greater; if both are heated alike, there will be no current.

215. Such a bundle of bismuth and antimony needles has been constructed to serve as a thermometer for delicate experiments on heat. Differences of temperature that are imperceptible by the mercury or alcohol thermometer, are found to affect the galvanometer of a thermo-electric pile. Radiant heat especially can be detected with extraordinary accuracy by exposing one end of the bundle to the heating rays.

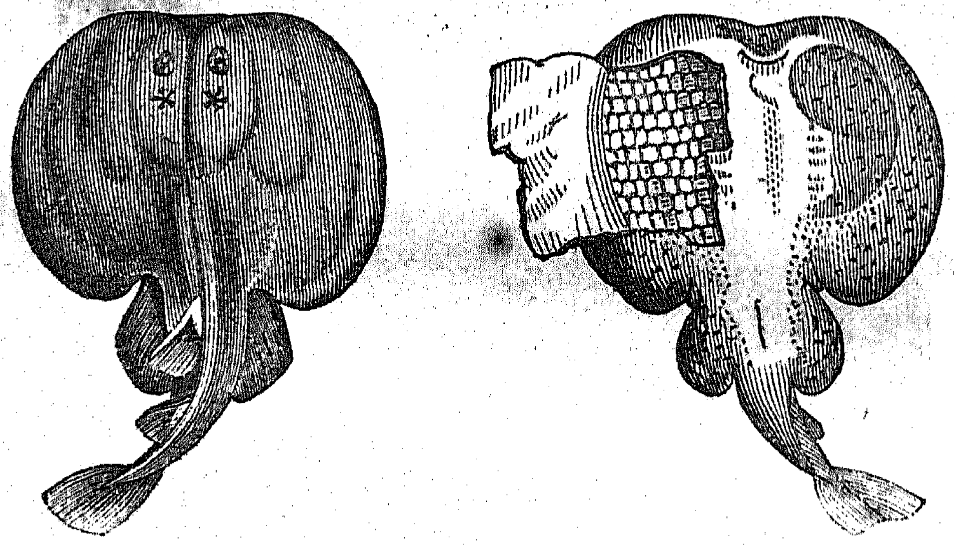
216. The current circulating in the thermo-electric circle is of weak intensity compared even with the voltaic pile, and therefore it is not adapted for giving shocks. But the quantity which it yields may be very great, and it is capable of decomposing chemical compounds. Also, by using a bundle of thirty elements or pairs about an inch thick, and heating one end by a hot iron placed near, and cooling the other with ice, the intensity of the current is sufficient to make a distinct *spark* in daylight, when the circle is broken or closed.

217. The discovery of thermo-electricity suggests an explanation of the probable origin of the earth's magnetism. The sun's rays heating the earth in one place after another in his daily circle, would cause an electric current to circulate round the globe in an equatorial direction, or more strictly, in the direction of his path. If we suppose him for a moment standing over any one place, it is obvious that the portion of the earth to the east of that place is hotter than the westerly portion; because what he has been recently shining on must be warmer than the ground he is only approaching to shine on after a day's absence. But we have seen that, in the thermo-electric circuit, negative electricity flows from the joining to the hot side, and positive electricity to the cold side; therefore the motion of the sun from east to west will cause a positive current to move in the same direction, and a negative current from west to east. But if we refer to the rule for determining what would be the magnetic polarity of the earth arising from such a current according to the laws of electro-magnetism, we find that it would give to each hemisphere the same kind of polarity as they actually have. If the daily path of the sun were from west to east, the earth's magnetism would be the reverse of what it is: so that the sun's heat circulating round the globe will necessarily magnetise the earth. The daily and yearly fluctuations of the needle also tend to show the connection of terrestrial magnetism with the sun's motions. It may therefore be said that the sun is the great source of all power on the earth. It gives warmth, supports vegetation, draws up the water to the clouds, originates the thunder and lightning, and produces magnetism and all its consequences. The earth's own forces of gravitation and cohesion, and its attractions in general, tend to aggregate, solidify, and condense the whole of its substance into a compact heap of lifeless matter; the sun supplies the counteractives of these, and causes expansion, separation, decomposition, and all the agencies which lead to the renewal of movement and life.

ANIMAL ELECTRICITY.

218. This branch of the science refers to the production of electricity by living bodies, and gives an account of certain animals that possess within their structure special organs for generating electric currents; it may also include what is known of the effects of electricity on the animal system. The former subject would be named Animalo-Electricity, if we followed the analogy of the preceding names—Magneto-Electricity, Thermo-Electricity.

219. There is a flat fish found on the shores of the Mediterranean, and on the Atlantic coast of France, which has been known from antiquity to give benumbing shocks to any one who handles it. It is called the *Torpedo*. When dissected, there are found in it two organs, or masses of honeycomb structure (see fig.), one on each side of the body at its broadest part, or near the head. In an animal 18 inches long, 12 broad, and 2 thick, each organ is about 5 inches long; the breadth is 3 inches at the head, and at the other end half an inch; being, as it were, triangular, the narrow end pointing to the tail. They occupy the whole thickness of the fish from breast to back, as far as they extend; they consist of a mass of roundish columns, whose direction is from breast to back, or upright when the fish lies flat. Each of these columns seems to be made up of a succession of distinguishable layers piled upon one another, and separated by mucous partitions; hence it has been supposed that the electricity is produced in the same manner as in the pile of Volta, or that the entire organ is an immense bundle of piles lying side by side, conspiring altogether to make an electric charge. The number of columns in each



organ depends on the size of the fish; in the one whose dimensions are stated above, 470 were counted in each; but as many as 1182 have been seen in a very large specimen. The number of layers or distinguishable partitions in a column an inch long has been found to amount to 150. A very large supply of nerves is afforded to the organs; they ramify into each column, and are distributed to the partitions—every partition receiving a nervous filament.

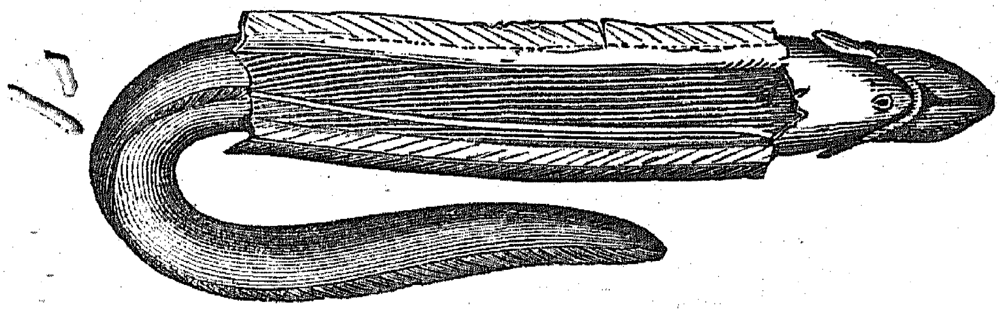
220. The back of the animal is positive, and the breast or belly negative, and the currents pass through the body between the breast and back. On touching either side, a shock is received; but by seizing the animal, and holding it by both sides, a much more intense shock is felt. In a second or two after receiving one shock, the charge accumulates, and discharges itself again, and thus a succession of shocks may be given, until the strength of the animal is exhausted. The electricity has to the feeling the same character as a discharge of very small Leyden jars; the intensity is small compared with machine charges, but equal to that of a very numerous voltaic pile. It is capable of magnetising iron, and of decomposing compounds; but its quantity being small, these effects are not produced to any great extent. Its use to the animal seems for defence against attacks, and as an offensive weapon generally; instead of devouring and destroying by the teeth, it launches its diminutive thunderbolts upon all creatures that approach it.

221. A second animal endowed with electrical organs is that called the *Gymnotus Electricus*, or electrical eel, found in various parts of America. It was seen in great numbers by Humboldt in the swamps of the Orinoco in South America. Its common length is about five feet, but it often occurs much larger. Its shocks are far more formidable than the discharges of the torpedo; men, and even horses, going into the water are stunned by its touch, and are frequently drowned before they have time to recover. The following description by Humboldt of the method adopted by the Indians for catching the gymnoti, completely illustrates their character and habits. They bring a troop of wild horses, and cause them to enter a muddy pool where they are contained. "The extraordinary noise caused by the horses' hoofs makes the fish issue from the mud, and excites them to combat. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organisation, furnishes a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surround the

pool closely; and some climb upon the trees, the branches of which extend horizontally over the surface of the water. By their wild cries, and the length of their reeds, they prevent the horses from running away, and reaching the banks of the pool. The eels, stunned by the noise, defend themselves by the repeated discharge of their electrical batteries. During a long time they seem to prove victorious. Several horses sink beneath the violence of the invisible strokes which they receive from all sides on organs the most essential to life, and, stunned by the force and frequency of the shocks, disappear under the water. Others, panting, with mane erect, and haggard eyes expressing anguish, raise themselves, and endeavour to flee from the storm by which they are overtaken. They are driven back by the Indians into the middle of the water; but a small number succeed in eluding the active vigilance of the fishermen. These regain the shore, stumbling at every step, and stretch themselves on the sand, exhausted with fatigue, and their limbs benumbed by the electric shocks of the gymnoti. In less than five minutes two horses were drowned. The eel being about five feet long, and pressing itself against the belly of the horses, makes a discharge along the whole extent of its electrical organ. The horses are drowned, from the impossibility of rising amid the prolonged struggle between the other horses and the eels. By degrees the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. They require a long rest and abundant nourishment to repair what they have lost of galvanic force. The mules and horses appear less frightened; their manes are no longer bristled, and their eyes express less dread. The gymnoti approach timidly the edge of the marsh, where they are taken by means of small harpoons fastened to long cords. When the cords are very dry, the Indians feel no shock in raising the fish into the air. In a few minutes our party obtained five large eels, the greater number of which were but slightly wounded."

222. In the gymnotus the structure of the electrical organ is not the same as in the torpedo. It occupies nearly four-fifths of the length of the animal, and is formed of thin plates lying in the direction of its length (see fig.); so that one end of the pile is at the tail and the other end near the head. Hence its shocks are most powerful when it brings both head and tail into contact with another animal. There are two pairs of organs, and their total bulk amounts to about one-third of the whole body of the fish. Two rows of small yellow spots are seen running along the back from head to tail, and every spot contains an opening which gives forth a mucous matter, which

covers the skin, and is found to be a remarkably good conductor of electricity.



223. In the rivers of Africa—in the Senegal, the Niger, and the Nile—is found a third species of electrical fish, called the *Silurus Electricus.* It is about twenty inches long. It is caught and eaten by the Egyptians. Its electrical organs lie beneath the skin all round the animal, and are less complicated than in the torpedo and gymnotus. Various other electrical fishes have been met with.

224. In all these animals the electrical apparatus is an addition to the ordinary vital organs, and its action is quite independent of them. It is not involved in the operations of digestion, circulation, or movement; but, like all other organs, it is supplied with nerves from the brain. It seems to be under the control of the animal to about the same degree as its moving apparatus. Although the structure of the organ is somewhat similar to a voltaic arrangement, and the shock the same as would be felt from a battery made up of several hundreds of small plates in a weak solution, it is not completely proved that it operates on the principle of the pile.

225. Apart from the possession of special apparatus, the operations of the animal body are such as to evolve electricity in many ways. The chemical processes of digestion and respiration—the constant passage of heat to and fro—the mechanical movements—may all generate electricity. The most common case of the appearance of excitement in the human subject, is when the clothes are stripped from the skin in a very dry air. When silk stockings are taken off, they sometimes cause a crackling noise, accompanied with sparks, which may be distinctly seen in the dark. If the skin and clothes are perfectly dry, this effect would probably be constant, as it is a mere effect of the friction. In very dry climates, where the atmosphere is so deficient in moisture as to keep all surfaces in a dry state, the observation is very familiar; it is also observed in rooms heated by stoves, which have the same excessive desiccating tendency.

226. Of the entire amount of electricity produced by the interior processes of the human body, only a small portion can appear in a free state on the surface; the greater part must be consumed again or discharged in other operations. In as far as the skin acquires a charge, its general character is found to be positive; but the amount differs very much in different individuals, and in the same individual at different times. A development of positive electricity seems to be identified with the health, vigour, and freshness of the body; for it diminishes, and is changed into negative, by great exertions and fatigue, by lassitude and cold. A sudden fit of violent exertion will in an instant convert the positive charge into a negative one. We may therefore suppose that the operations of nutrition are constantly generating positive electricity, while exertion and the wasting operations generate negative; that the nourishing processes are like the cells of the voltaic pile, where, by the consumption and chemical transformation of material, the excitement is produced; and the wasting operations like the place of action in the circuit, where the excitement is expended in producing effects of heat, decomposition, or moving power. Liebig has found that the juices of the flesh or muscle are constantly acid, while the blood in the arteries and veins circulating through the flesh is alkaline. But an acid and alkali, with a membrane between them, are capable of causing a current, the acid being positive, and the alkali negative; so that the blood would from this cause have a negative charge, and the flesh a positive charge.

227. The effects of electricity on the animal system are as yet very little understood. Electric shocks have been applied as remedies for diseases, and have often been productive of good. The chief disorder where they are found valuable is the case of paralysed limbs. By passing a long-continued series of discharges through a torpid arm or leg, it has often been restored to vigour. For this purpose the ordinary friction machine has been commonly employed; but it is supposed that the magneto-electric machine may prove a much more powerful stimulant. Relief has been given also to patients suffering from tic.

228. It may be surmised, that if the human body in its ordinary healthy state contains a surplus of positive electricity, and if the earth is in general negative, there is a propriety in keeping some insulating substance between the feet and the naked ground. We may thus assign an additional reason for the disagreeable and unhealthy effects of damp feet; for besides cooling down the system, the moisture will

conduct away the body's free electricity to the earth, and with this a certain portion of the vigour of the frame. On the same principle fogs, which are commonly negative, by enveloping the person, must take away its positive electricity; and their unpleasant action may in some measure be owing to this cause. The sudden and frequent changes of the state of the atmosphere before and during a thunderstorm, are very distressing to many people. On the whole, therefore, it may be safely affirmed that human comfort is affected to a very considerable degree by the electrical phenomena of nature.

229. The actions of vegetable life are such as cannot fail to be attended with the evolution of electricity. The great range of chemical decompositions and combinations which go on during the growth of plants, is a sufficient cause of an abundant electrical excitement. Observations and experiments have shown that this actually occurs; there is a constant circulation of electricity of feeble tension in living vegetables. But although there is too little insulation or resistance by bad conductors, to cause this electricity to assume a high intensity, so as to give shocks or sparks, the quantity of it may be very great, and it may contribute in some essential ways to the maintenance of the organic life. If we consider that electrical currents are the means of conveying chemical force from one place to another, we may easily imagine that this conveyance is sometimes necessary in the growth of vegetables. A certain power evolved at the roots in the earth, or at the leaves in the air, may be required in other parts of the plant. The decomposition of the seed may give birth to an electric current which effects important changes in the expanding germ. It has been found that by causing the seed to assume an electric state opposite to what it naturally assumes, its development is retarded or checked. Hence, on the other hand, it is perfectly credible that the growth of plants may be very much quickened by communicating electricity to them by artificial methods. Minute and long-continued observation, however, is yet required to enable us to state with accuracy the precise functions of electrical excitement in organised bodies.

ANIMAL MAGNETISM.

230. Besides the well-known effects on the human system of electrical shocks, either from friction machines, from voltaic piles, or from magneto-electrical apparatus, a totally different kind of influence has for some time back been asserted to arise

from the action of magnets. This influence is said to be felt most intensely by persons suffering under disease of the nerves, and it is capable of producing extraordinary states of body and mind. There is great difficulty in getting the exact truth contained in observations about the human feelings, especially when men's minds are excited by the sentiment of the marvellous. But the knowledge now possessed on the whole subject of electricity, coupled with some experiments of an accurate kind lately performed, enable us to make a few statements on this subject which will not appear inconsistent with the rigour of a scientific work.

231. In the first place, it is an inevitable consequence of Faraday's discovery of magneto-electricity, that a magnet pointed to the back, the arm, the leg, or any other part of the human body containing a considerable nerve, and moved along in the course of the nerve, must produce, by magneto-electric induction, a current of electricity. The effect will be nearly the very same as a weak current from the magneto-electric machine. The influence of a magnet thus passed up and down over the body will be a perceptible thing; there will be imparted a current in one direction while it is moved one way, and an opposite current when it is moved the other way, and all the effects will arise which are caused by electric currents in the first place, and by the frequent reversing of them in the second place. Any one may confirm by their own experience the truth of this necessary inference from the laws of magnetic induction. In the generality of people a very weak magnet may produce an indubitable sensation; and by using magnets of a higher power, the effect will be so decided as to be felt by every one.

232. But it is now asserted by Baron Reichenbach (and the assertion is supported by experiments of a trustworthy character), that magnets have on certain very nervous persons an influence of a kind totally distinct from the above. The magneto-electric induction is produced only so long as the magnet is kept in motion, this being the essential condition of the induction. If a person pretend to feel any action from a magnet while both he and it are at rest, it cannot be from an electric current, or from the proper electric influence of the magnet. But, according to Reichenbach, there are some individuals who see on a magnet in the dark aurora flames streaming out from the poles and along the edges of the bar. It has been proved that this light is a real existence, and not a mere fancy of diseased nerves, by its acting on Daguerreotype plates like ordinary solar light; so that the inference is, that magnets are actually luminous, but with a degree of lumi-

nosity so very feeble, that even in pitch dark it cannot affect ordinary eyes.

233. Besides the luminous phenomena of a magnet, it has [illegible] found able to act upon the system of sensitive patients in [illegible]s ways. The hand of the patient is said to follow it by a mysterious attraction; and when the arm or any other part is streaked with it, a sensation is produced which in one direction feels cool and in the other warm; or opposite poles, drawn in the same way, will cause opposite sensations. Moreover, by streaking any object, such as a glass of water, the patient is aware of a change having come over it. By the action of magnets, intense pleasure or violent uneasiness may be communicated to susceptible persons; and this effect arises also from the magnetism of the earth; for such persons feel a degree of suffering amounting to illness when they lie in bed with their heads to the west and feet to the east; whereas they enjoy perfect repose in the direction of the magnetic meridian—the head being to the north.

234. But to show that this influence is not the result of the ordinary magnetic property of loadstone or the electro-magnet, it is alleged to arise from *crystals* also, which have no magnetic action in general. A crystal presents all the appearances—of illuminated poles, attraction for the hand, and cool and warm sensations, according to the pole used. It follows, therefore, that the power of a magnet over highly-sensitive people is something additional to its recognised properties, and common to it with crystals.

235. A recent discovery of Faraday gives considerable support to the assertion of a common influence in magnets and in crystals; and although it does not actually prove the statements of Reichenbach, it serves to take off the air of incredibility that might otherwise surround them. So explicit are Faraday's observations, that they have led him to assert the existence of a *new magnetic condition*, or a *new magnetic force*—that is to say, a power possessed by magnets perfectly distinct from their attraction for iron. Moreover, this force is shown by its action on *crystals*.

236. When a ray of light is reflected at a certain angle from a mirror, it is polarised, or acquires such a property that a second reflection in a particular way will extinguish it. Light is likewise polarised by passing through certain transparent bodies; and the effect always is, that after the second action, the ray appears only in one position of the second substance; in other positions it is extinguished. Faraday employed a polarising apparatus, consisting of a mirror to give the first influence, and a transparent body for the second;

so that after a reflection and a transmission, the light was reduced to the state of partial appearance. In the course of the ray from the mirror to the *eye-piece* (as the second polarising substance is called), he placed a crystal so that th ray must pass through it. This crystal of itself h[illegible] polarising influence; but if it is arranged so as to lie between the poles of a powerful electro-magnet, when the magnet is rendered active, the crystal instantly becomes charged with an influence which is made known by a change in the appearance of the polarised ray after it has passed through the eyepiece. If, before the magnetism is set on, the eye-piece i arranged that the polarised ray is visible, after complet the circuit the ray is made *invisible*. It is not, howeve destroyed or entirely extinguished; for if the eye-piece i turned round somewhat to one side, it reappears. So if the eyepiece is first placed in the position in which the polarised ray is extinguished, the action of the magnetism on the intervening crystal will bring it into view; and the eye-piece must again be rotated, in order to cause the same extinction as before the magnetism was made active. Hence the power of a magnetised crystal is expressed by saying that it makes a polarised ray to *rotate;* for the ray's positions of appearance and disappearance are so far changed, that the eye-piece must be revolved to one side or another to bring them out.

237. There is thus an influence possessed by magnets over the atoms of crystals, whereby these give a bias different from their ordinary action to all rays of light that pass through them. Something common must attach to one constituent of magnetic force and one constituent of crystalline force, in order that the one may overpower or modify the other; for forces which act and react on each other must be similar in kind. The crystal, while under the magnetic influence, acquires no attraction for iron, nor any other feature of common magnetism; and therefore it is alleged with justice that a power altogether new and different is hereby made manifest. Thus both the results of Faraday, and the observations of Reichenbach, point to a power over and above common electricity, although of the true polar character; for Faraday found that the reversal of the poles of the magnet reversed the direction of the rotated ray: in one case the ray had to be sought by revolving the eye-piece to the right; and with reversed poles it reappeared by revolving the eye-piece to the left.

238. But Reichenbach found his new force in many other quarters besides magnets and crystals. It arises from the sun's rays, the moon's rays, from heat without light, from

friction, from chemical action, and from the human hand; and it seems also present in some degree in the material world at large; so that to the sensitive patient all nature is illuminated in the deepest gloom of midnight. A faint luminous [illegible] of varied colours appears all over the objects of a room, the persons, and especially the hands of human beings, and over dead bodies and recently occupied graves. On the whole, it is impossible not to be struck with the connection which the new magnetic condition has with light in the very dissimilar experiments of Reichenbach and Faraday.